BOKU University, Vienna

Department of Landscape, Water and Infrastructure

Institute of Hydrology and Water Management

Rainfall-Runoff-Model COSERO

HANDBOOK v2026.1

M. Herrnegger, C. Ehrendorfer, and H. Zeitfogel

With earlier inputs by D. Klotz, J. Wesemann, S. Frey, T. Senoner, K. Schulz, H.P. Nachtnebel

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1 TABLE OF CONTENTS

1 TABLE OF CONTENTS II

1. INTRODUCTION 1

2. RAINFALL-RUNOFF-MODEL COSERO 3

2.1 MODEL DISCRETIZATION, STRUCTURE, VARIABLES, AND PARAMETERS 4
2.2 INPUTS 13
2.2.1 Rainfall & snow 13
2.2.2 Potential evapotranspiration 14
2.3 ACTUAL EVAPOTRANSPIRATION 15
2.4 INTERCEPTION MODULE 17
2.5 SNOW MODULE 18
2.5.1 Description of the snow cover 19
2.5.2 Computation of the soil temperature 20
2.5.3 Computation of the reduction of the snow melt factor 20
2.5.4 Computation of the potential snow melt factor 23
2.5.5 Checking for water bodies 24
2.5.6 Is there any snow? 24
2.5.7 Fresh snow density 24
2.5.8 Statistical description of the temperature field of a grid cell 24
2.5.9 Computation of potential snow melt 25
2.5.10 Potential sublimation of snow 25
2.5.11 Transition of snow to glacier ice 26
2.5.12 Does snowfall occur? 26
2.5.13 Is the computation of snowmelt necessary? 26
2.5.14 Computation of actual snow melt 26
2.5.15 Computation of the actual water holding capacity 27
2.5.16 Calculation of fluxes inside the snowpack and leaving the snowpack 27
2.5.17 Refreezing water 29
2.5.18 Heat loss of the snowpack 29
2.5.19 Update the amount of liquid water in the snowpack 29
2.5.20 Computation of new snow density, snow depth, and coverage 30
2.5.21 Computation of the zone values 30
2.6 GLACIER MODULE 32
2.6.1 Is the cell glacierized? 33
2.6.2 Initial thickness of the ice layer 33
2.6.3 Conversion of snow into ice 33
2.6.4 Glacier melt 33
2.6.5 Routing of glacier melt 34
2.7 SOIL MODULE 35
2.7.1 Water balance of soil module 35
2.7.2 Inflow to soil module 35
2.7.3 Actual Evapotranspiration from soil 35
2.7.4 Soil temperature $TSOIL_t$ (calculated in snow module) 37
2.7.5 Correction of $ETAG_t$ for snow sublimation (for TSOIL < 0) 37

2.7.6 Fast runoff from soil module *37*
2.7.7 Percolation from soil module (if TSOIL > 0°C) *38*
2.7.8 Total outflow from soil module *38*
2.8 (NON-) LINEAR RESERVOIRS 39
2.8.1 Surface flow *39*
2.8.2 Interflow and baseflow *40*
2.8.3 Zone routing *42*
2.9 ADDITIONAL EXTERNAL INFLOW 43
2.9.1 Direct input: Qaddinflow *43*
2.9.2 Internal calculation: Qreginflow *44*
2.10 DIVERSIONS 44
2.11 SIMULATED RUNOFF 45

3. MODEL ENVIRONMENT 46

3.1 INPUT FILES 46
3.1.1 Defaults file – Defaults.txt *46*
3.1.2 Parameter file *48*
3.1.3 Meteorological data *49*
3.1.3.1 Definition of meteorological input - MetDefaults.txt 49
3.1.3.2 Precipitation 49
3.1.3.3 Temperature 50
3.1.3.4 Potential evapotranspiration 50
3.1.4 Runoff data *50*
3.1.5 Additional runoff data (qaddinflow) *51*
3.1.6 Regression parameters (qreginflow) *52*
3.2 OUTPUT FILES 52
3.2.1 Statevar file - statevar.dmp *55*
3.2.2 Statistics file – statistics.txt *57*

LIST OF TABLES 59

LIST OF FIGURES 60

APPENDIX 62

LIST OF PUBLICATIONS IMPLEMENTING COSERO 62
PARAMETER TABLES 65
Landcover Classes (NC_) *65*
INTMAX *65*
ETVEGCOR *66*
CORINE Landcover Classes *67*
ESTIMATION OF COSERO PARAMETERS FROM SPATIALLY DISTRIBUTED SOIL HYDRAULIC MAPS 68

BIBLIOGRAPHY 69

1. Introduction

The COSERO model (COntinuous SEmi-distributed RunOff) is a continuous, (semi-)distributed conceptual rainfall-runoff (R-R) model developed at the Institute of Hydrology and Water Management (HyWa, formerly IWHW). The concept is similar to the HBV model (Bergström 1992). It accounts for the accumulation and melting of snow and glaciers, actual evapotranspiration, interception, soil water storage, separation of runoff into different flow components, and routing via a cascade of linear and nonlinear reservoirs.

The COSERO model evolved from a model structure that was originally developed for forecasting runoff of the river Enns in Austria (Nachtnebel et al. 1993). Since that time, substantial improvements have been incorporated into the model, including enhancements to the snow module by Fuchs (1998) and the ability to perform automatic parameter calibration (Kling 2002). Further modifications were made over the years, e.g., for the application of the model in real-time flood forecasting systems in Austria and neighboring countries, for the consideration of distributed routing or implementation of new optimization methods.

Since 1993, different versions of COSERO have been successfully applied in numerous scientific and commercial projects all over the world. The simulations were performed in different spatial scales, ranging from plot scale to catchments of thousands of square kilometers. For water balance studies, the model was applied in a monthly temporal resolution, but also in a temporal resolution of 15 minutes for flood forecasting systems.

The COSERO model has been widely applied in various hydrological studies and applications. It has been used for climate change impact assessment, as well as hydrological modeling studies and applications, including simulating the water balance of several hundred catchments. Additionally, COSERO has been utilized for forecasting and real-time applications in flood forecasting and runoff prediction systems. An inverse modeling approach has also been developed based on COSERO, using runoff observations as input to calculate areal rainfall. The model has been further applied for model development and parameter estimation studies, as well as large-sample hydrology and data-related research.

Table 8 in the Appendix provides an overview of different publications in which COSERO was applied.

The current model development at BOKU-HyWa focuses on implementing regionalization strategies and optimizing model parameters (Klotz et al. 2015, Schulz et al. 2015, Klotz et al. 2017b). Spatially distributed information of the catchment, e.g., elevation, slope, aspect, solar radiation, land use, or soil information, is thereby used to estimate parameters of a priori defined transfer functions. These transfer functions are, consequently, used to estimate the model parameters. The approach is similar to methods proposed by Samaniego et al. (2010). It has the advantage of significantly reducing the number of parameters to estimate during optimization and potentially overcoming the scale dependence of model parameters. A second avenue for estimating distributed model parameters is the use of machine-learning-based parameter fields (Zeitfogel et al. 2025). Apart from the implementation of parameter regionalization, other changes

have been made in the model code, including (i) splitting of subroutines in separate files for greater clarity, (ii) dynamical allocation of arrays to enable the simulation of larger regions in high temporal resolutions, (iii) global definition of variables to more easily implement new developments and (iv) parallelization of the model code via openMP to enhance computation time. Improvements have also been implemented to include additional process representation, e.g., glacier melt or anthropogenic diversions.

This handbook aims to provide (i) a detailed description of the model flow, the parameter sets, system states, and fluxes, and (ii) an overview of the model environment, outlining the structure and contents of the relevant input and output files. This includes basic guidance on compiling the model code in FORTRAN, generating the model topology in GIS software or R, and preparing various data and settings files. Furthermore, guidance is provided on the calibration procedure and the use of additional software tools, which can be helpful in the hydrological modeling process.

While this is a major update to the handbook compared with the 2015 version, the model is continuously evolving. If any algorithms have changed or are insufficiently described, or if additional assistance with model setup or application is needed, please contact hywa_office@boku.ac.at.

2. Rainfall-Runoff-Model COSERO

The COSERO model accounts for accumulation and melting of snow and glaciers, actual evapotranspiration from interception, snow and soil layers, storage of water in the soil, and the separation of runoff into different runoff components (surface flow, interflow, and baseflow) by means of a cascade of linear and nonlinear reservoirs. The model is spatially distributed. All inputs, outputs, and parameters have a spatial dimension. For the sake of better readability, this attribute is omitted in the model formulations in the following sections.

COSERO is formulated in a state space formulation with state transition functions (1) and output functions (2).

$$\dot{S}_t = f(\dot{S}_{t-1}, \dot{I}_t) \quad (1)$$

$$\dot{O}_t = g(\dot{S}_{t-1}, \dot{I}_t) \quad (2)$$

$\dot{I}_t$	Input	mm/dt
$\dot{O}_t$	Output	mm/dt
$\dot{S}_t$	System states	mm
Δt	Model time step	-

Figure 1 shows a schematic representation of the state formulation.

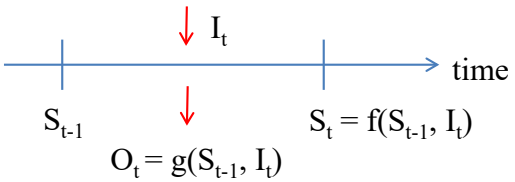


Figure 1. Schematic representation of the state formulation with system states S, input I, output O, and time t.

State-space formulations are commonly used in hydrological modeling to represent the dynamic behavior of complex water systems. In the hydrological context, the state variables typically represent different components of the water cycle, such as soil moisture, groundwater storage, snow accumulation, and surface water storage.

The state-space approach allows COSERO to capture the temporal evolution of these state variables in response to various inputs, such as precipitation, evapotranspiration, and human interventions (e.g., water withdrawals, reservoir operations). The state transition function, as shown in equation (1), describes how the state variables change from one time step to the next, based on the previous state and the current inputs. The output function, as depicted in equation (2), then relates the state variables to the hydrological outputs of interest, such as streamflow, groundwater levels, or reservoir storage. This allows the model to simulate and predict the behavior of the hydrological system, which is necessary for water resources management, flood forecasting, and climate change impact assessments.

2.1 Model discretization, structure, variables, and parameters

The model uses different spatial modeling units to represent a river catchment. The catchment can be divided into several subbasins (NB). For the outlet of each subbasin, the model computes a simulated discharge (QSIM). To account for the physical heterogeneity within the subbasin, a further subdivision into hydrological response units (HRUs, Wood et al. (1988)) is possible. These HRUs or *model zones* (NZ) can be "classically" generated with information such as (sub-) catchment boundaries, elevation zones, soil, and land cover information. However, with increasing computational power, a gridded approach has become more popular, with grid sizes of 1x1km or finer.

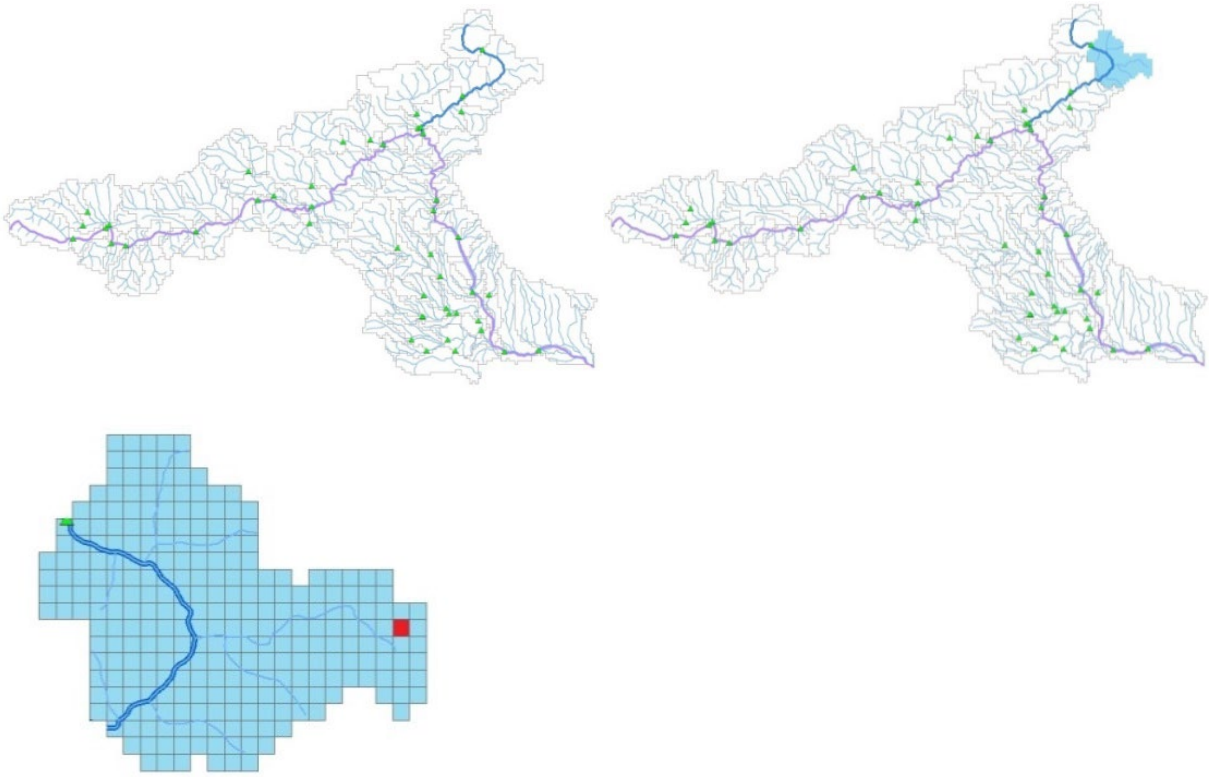


Figure 2. Illustration of the spatial discretization of the Mur catchment. The overall catchment is subdivided into smaller sub-catchments, which are then further divided into a finer grid of spatial units. This hierarchical spatial representation allows the model to capture the heterogeneity of the catchment and the underlying hydrological processes at different scales (Burgholzer 2017).

The zones (NZ) are the basic spatial modeling units. Each zone has a set of parameters, receives an input, and simulates the modules described in the following sub-chapters to compute a zone output. Within the subbasin, the outflow of the zones, together with inflow from upstream zones, is routed to the basin outlet and forms the subbasin runoffs. Figure 3 shows the model structure, model parameters, system states, and fluxes. Important variables are listed in Table 1.

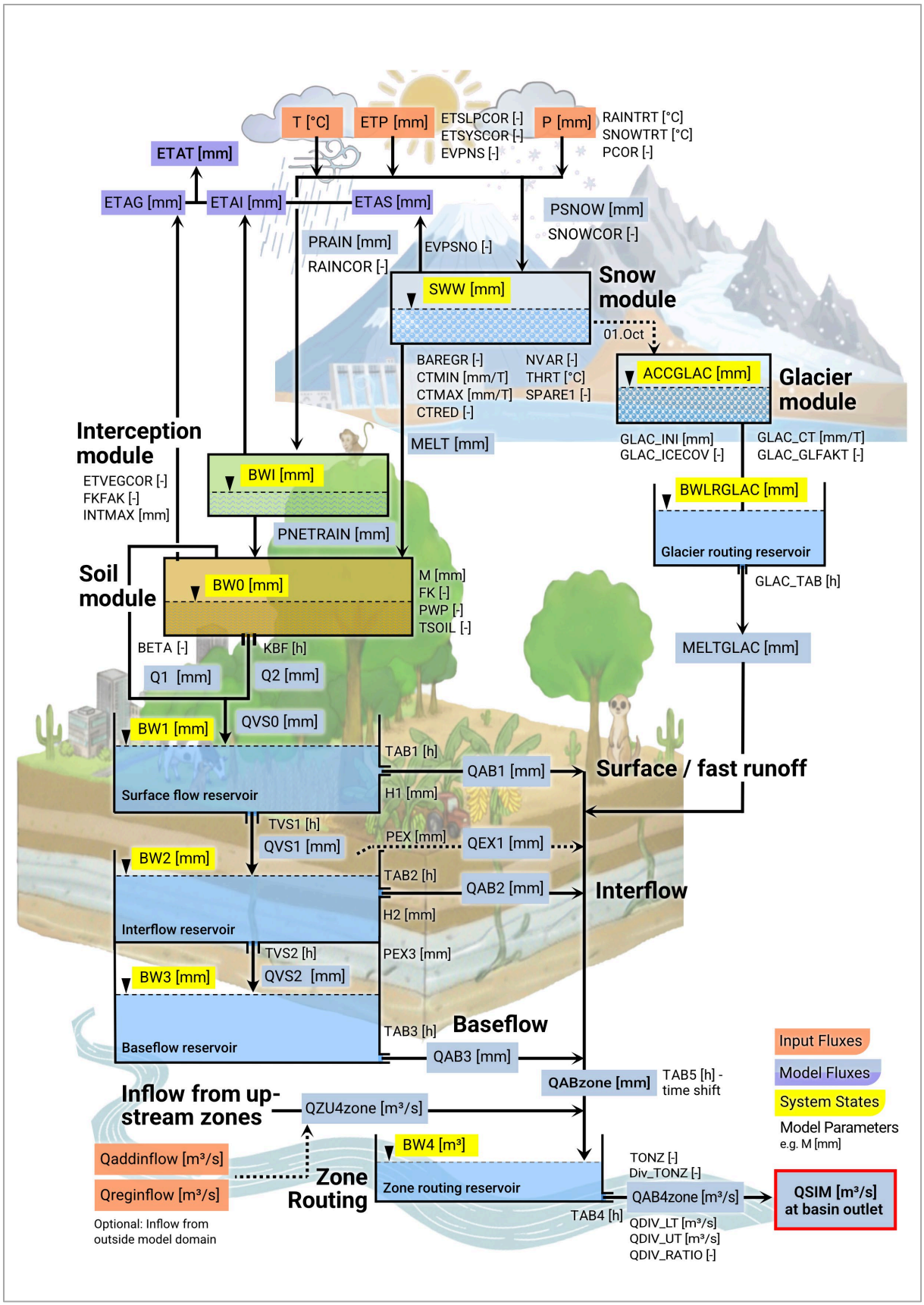


Figure 3. COSERO model structure, including model parameters, system states, and fluxes.

Table 1. Important variables of the COSERO model. Flux variables represent sums over the time step. State variables give the water storage at the end of the time step.

Variable	Units	Type	Description
P	mm	Input	Precipitation (sum over time step)
T	°C	Input	Air temperature (average over time step)
ETP	mm	Input	Potential evapotranspiration (sum over time step)
PZON	mm	Input	Corrected precipitation (sum over time step)
PRAIN	mm	Flux	Liquid precipitation / rainfall
PSNOW	mm	Flux	Solid precipitation / snow
BWI	mm	State	Water stored in interception reservoir
ETAI	mm	Flux	Actual evaporation from interception storage
PNETRAIN	mm	Flux	Net-rainfall after interception, reaching the soil module
JDAY	-	-	Julian day of the year starting on 22 December
SMELT	mm	Flux	Actual snowmelt
SWW (SWE)	mm	State	Snow water equivalent
ETAS	mm	Flux	Snow sublimation
ACCGLAC	mm	State	Glacier ice water equivalent
BWLRGLAC	mm	State	Water stored in glacier routing reservoir
MELTGLAC	mm	Flux	Glacier melt
BW0	mm	State	Water stored in soil reservoir
ETAG	mm	Flux	Actual evapotranspiration from soil module
ETAT	mm	Flux	Total actual evapotranspiration
Q1	mm	Flux	Fast runoff from soil module
Q2	mm	Flux	Percolation from soil module
QVS0	mm	Flux	Total runoff generation from soil module (Q1+Q2)
BW1	mm	State	Water stored in surface flow reservoir
QAB1	mm	Flux	Fast / Surface flow
QVS1	mm	Flux	Percolation to interflow reservoir
BW2	mm	State	Water stored in interflow reservoir
QAB2	mm	Flux	Interflow
QEX2	mm	Flux	Excess runoff when interflow reservoir is full
QVS2	mm	Flux	Percolation to baseflow reservoir
BW3	mm	State	Water stored in baseflow reservoir
QAB3	mm	Flux	Baseflow
QABzone	mm	Flux	Total zone runoff
Qaddinflow	m^3/s	Input	Optional: external inflow
Qreginflow	m^3/s	Flux	Optional: regression-based external inflow
QZU4zone	m^3/s	Flux	Inflow from upstream zones
BW4	m^3	State	Water stored in zone routing reservoir
QAB4zone	m^3/s	Flux	Outflow from zone routing reservoir
QSIM	m^3/s	Flux	Simulated basin runoff

The parameters are spatially distributed across the subbasin and have the dimensions *NB, IZ/NZ*. Some parameters also include a temporal dimension, such as mean monthly temperature (TMMON) or monthly precipitation correction factors (PCOR).

Table 2. Model parameter dimensions.

Dimension of parameter	**Description**
NB	Subbasin
IZ	Zone number within subbasin
NZ	Zone number within model
NM	Month
NC	Vegetation / land cover class
IKL	Total number of snow classes
IZONE	Total number of zones per subbasin
NBASIN	Total number of subbasins
NCLASS	Total number of vegetation / land cover classes

The following Table 3 lists all model parameters that can theoretically be configured in the parameter file. Some parameters are defined a priori based on land use, vegetation, topographical, or geological information (e.g., ELEV, ETVEGCOR, INTMAX, CTMIN, CTMAX, or M), while others are used with the default values. Table 3 also includes the column "Frequently used" to indicate whether parameters are frequently modified or the default values are employed.

Table 4 shows the model topology, which must also be defined in the parameter file.

Table 3. Description of all model parameters. ***Sensitive*** *ones are denoted in bold, and those also typically* ***<u>included in model calibration</u>*** *in bold and underlined.*

Parameter	***Dimension***	***Type***	***Unit***	***Description***	***Default value***	***Typical values***	***Remarks***
BAREGR	NB, IZ	float	/	fraction of ground that is never snow covered - use for steep rocky areas in high elevation	0	0	
<u>BETA</u>	NB, IZ	float	/	parameter to compute runoff generation as a function of soil moisture	4.5	0.1 - 10	can be derived from soil maps (Table 13)
BW0INI	NB, IZ	float	mm	initial soil moisture of the soil layer	0.7	-	insensitive with continuous simulation after spin-up time
BW1INI	NB, IZ	float	mm	initial water level in the surface flow reservoir (insensitive with continuous simulation)	0	-	insensitive with continuous simulation after spin-up time
BW2INI	NB, IZ	float	mm	initial water level in the inter flow reservoir	25	-	insensitive with continuous simulation after spin-up time
BW3INI	NB, IZ	float	mm	initial water level in the base flow reservoir; or observed runoff at the start of the simulation period	250	-	insensitive with continuous simulation after spin-up time
BW4INI	NB, IZ	float	mm	initial water level in the subbasin route reservoir (insensitive with continuous simulation)	0	-	insensitive with continuous simulation after spin-up time
<u>CTMAX</u>	NB, IZ	float	mm/°C/d	maximum snow melt factor on June 21	5	4 - 12	
<u>CTMIN</u>	NB, IZ	float	mm/°C/d	minimum snow melt factor on Dec 21	2	0.5 – 4	
CTNEG	NB, IZ	float	mm/°C/d	negative melt factor to compute refreezing of melted water in the snow layer	1	1	
CTRED	NB, IZ	float	/	factor to reduce the melt factor after snow fall because of higher albedo	0.7	0.7	
DAYSDRY	NB, NM	float	d	length of dry spells (monthly timesteps)	0	0	not used for time steps ≤ 24 h
DAYSWET	NB, NM	float	d	length of wet spells (monthly timesteps)	1	0	not used for time steps ≤ 24 h
DFZON	NB, IZ	float	km^2	area of zone			
DWHCAP	NB, IZ	float	$1/(g/cm^3)$	decrease of the water holding capacity with increasing snow density	0	0	
ELEV	NB, IZ	float	m	mean elevation of the zone	500	200 - 4000	

Parameter	*Dimension*	*Type*	*Unit*	*Description*	*Default value*	*Typical values*	*Remarks*
ETSLPCOR	NB, IZ	float	/	correction factor for potential evapotranspiration to account for slope and aspect	1	0.9 - 1.3	
ETSYSCOR	NB, IZ, NM	float	/	correction factor for ETP to account for systematic errors	1	0.9 - 1.3	
ETVEGCOR	NB, IZ, NC, NM	float	/	correction factor for potential evapotranspiration to account for vegetation type	1	0.4 - 1.3	
EVPNS	NB, IZ	float	mm/h	critical precipitation rate at which ETP is zero (~atmosphere saturated)	0.7	0.7	
EVPSNO	NB, IZ	float	/	correction factor for ETP to account for snow sublimation	0.7	0.7	
FK	NB, IZ	float	/	field capacity	1	0.08 - 0.42 / 1	if FK=1 and PWP=0; M = conceptual soil storage (recommended)
FKFAK	NB, IZ	float	/	factor to compute ETA from ETP as a function of soil moisture	0.7	0.3 - 0.9	
GLAC_CT_	NB, IZ	float	/	Factor to adjust snow melt factor for glacier	0.25	0.1 - 0.5	
GLAC_GLFAKT	NB, IZ	float	/	Radiation index	0.02	0 – 1	
GLAC_ICECOV	NB, IZ	float	/	fraction of zone covered by glacier	1	0 – 1	
GLAC_INI	NB, IZ	float	mm	initial glacier volume in mm water equivalent	99999	-	
GLAC_TAB	NB, IZ	float	h	recession constant for simulating routing within a glacier	8	1 – 10	
H1	NB, IZ	float	mm	outlet level of reservoir for simulating surface flow	2	0 – 20	can be derived from soil maps (Table 13)
H2	NB, IZ	float	mm	outlet level of reservoir for simulating interflow	10	0 - 20	can be derived from soil maps (Table 13)
INTMAX	NC, NM	float	mm	maximum storage capacity of interception module	0	0.5 – 6	
KBF	NB, IZ	float	h	recession constant for simulating outflow from the soil module with a linear reservoir	3000	1000 - 12000	can be derived from soil maps (Table 13)
KMELTRINI	NB, IZ	float	mm	initial amount of liquid water stored in the snow layer	0	0	insensitive with continuous simulation after spin-up time
KSHINI	NB, IZ,	float	mm	initial depth of the snow layer	0	0	insensitive with continuous simulation after spin-up time
KSWINI	NB, IZ	float	mm	initial water equivalent of the snow layer	0	0	insensitive with continuous simulation after spin-up time

Parameter	*Dimension*	*Type*	*Unit*	*Description*	*Default value*	*Typical values*	*Remarks*
M	NB, IZ	float	mm	storage capacity of the soil	300	20 - 6000	if FK=1 and PWP=0; M = conceptual soil storage (recommended); can be derived from soil maps (Table 13)
NC	NB, IZ	integer	/	land cover class of zone	-	1 - 9	
NSRHOMAX	NB	float	g/cm^3	maximum density of newly fallen snow	0.3	0.3	
NVAR	NB, IZ	float	/	variance for distributing new snowfall with a log-normal distribution	1.5	0.1 - 2.5	
PCOR	NB, IZ, NM	float	/	correction factor for precipitation (liquid and solid) (multiplicative)	1	0.8 - 2	
PEX2	NB, IZ	float	mm	unused, storage capacity of inter-flow reservoir	9999	-	
PEX3	NB	float	mm	unused, storage capacity of base-flow reservoir	9999	-	
PWP	NB, IZ	float	/	permanent wilting point	0	0.03 - 0.12 / 0	if FK=1 and PWP=0; M = conceptual soil storage (recommended)
RAINCOR	NB, IZ	float	/	correction factor of rainfall to account for systematic errors	1	0.8 - 2	careful of redundancy with PCOR
RAINTRT	NB, IZ	float	°C	transition temperature above which precipitation is pure rain (multiplicative)	3	-1 - 4	
SETCON	NB, IZ	float	/	settlement time constant as used in the settlement equation of Riley (1973)	0.2	0.2	
SNOWCOR	NB, IZ	float	/	correction factor of snowfall to account for systematic errors (multiplicative)	1	0.8 - 2	careful of redundancy with PCOR
SNOWDET	NB, IZ	integer	/	switch to decide if the form of precipitation shall be determined (1 = determine form of precipitation)	1	1	
SNOWTRT	NB, IZ	float	°C	transition temperature below which precipitation is pure snow	0	-2.5 - 3	
SOILTYPE	NB, IZ	integer	/	not used	1	-	
SPARE1	NB, IZ	float	NZ	activates snow transfer on Sep 30. (1 = no snow transfer)	1	-	
SPARE2	NB, IZ	float	NZ	not used	1	-	
SPARE3	NB, IZ	float	NZ	not used	1	-	

Parameter	*Dimension*	*Type*	*Unit*	*Description*	*Default value*	*Typical values*	*Remarks*
SRHOMAX	NB	float	g/cm^3	maximum density of the snow layer	0.45	0.45	
TAB1	NB, IZ	float	h	recession constant for simulating surface flow	50	1 - 50	can be derived from soil maps (Table 13)
TAB2	NB, IZ	float	h	recession constant for simulating interflow	250	25 - 300	can be derived from soil maps (Table 13)
TAB3	NB	float	h	recession constant for simulating base flow	5000	500 - 8000	
TAB4	NB, IZ	float	h	recession constant for routing within a subbasin	1	0.05 - 5	
TAB5	NB	float	h	time shift for QAB	1	0.1 - 10	
TCOR	NB, IZ, NM	float	°C	correction constant for air temperature (additive)	0	0 - 4	
THRT	NB, IZ	float	°C	threshold temperature above which snow melt is simulated	0	-2 - 3	
TMMON	NB, IZ, NM	float	°C	long-term mean monthly temperature	10	-25 - 12	
TSOILINI	NB, IZ	float	°C	initial soil temperature	5	5	insensitive to continuous simulation after spin-up time
TSOILMAX	NB, IZ	float	°C	maximum soil temperature	15	15	
TSOILMIN	NB, IZ	float	°C	minimum soil temperature	-5	-5	
TVAR	NB, IZ	float	°C	standard deviation of air temperature within the modeling time step for simulating snow melt	0	0 - 5	recommended at coarse temporal and spatial resolution
TVS1	NB, IZ	float	h	recession constant for simulating percolation from the surface flow module	100	5 – 200	can be derived from soil maps (Table 13)
TVS2	NB, IZ	float	h	recession constant for simulating percolation from the inter flow module	200	45 -500	can be derived from soil maps (Table 13)
UADJ	NB, IZ	float	mm/ (mbar/d)	average daily wind function during rain on snow events	2	2	
WATERBODY	NB, IZ	integer	/	switch to identify zones representing open water bodies (1 = open water body)	-	0/1	
WHCAP	NB	float	/	water holding capacity at the maximum snow density	0.05	0.05	

Table 4. Topology indices in the parameter file.

Parameter	Dimension	Type	Unit	Description	Default value	Typical values	Remarks
NB	NB, IZ	integer	/	index of subbasin	-	-	
IZ	NB, IZ	integer	/	index of zone within subbasin	-	-	
NZ	NB, IZ	integer	/	index of zone within model	-	-	
TONZ	NB, IZ	integer	/	NZ-index of zone into which zone flows	-	-	
Div_TONZ	NB, IZ	integer	/	NZ-index of zone to which water between QDIV_LT and QDIV_UT is diverted	-	-	
QDIV_LT	NB, IZ	float	m^3/s	lower threshold above which water should be diverted from zone	999	-	
QDIV_UT	NB, IZ	float	m^3/s	maximum amount of water that should be diverted from zone	999	-	
QDIV_RATIO	NB, IZ	float	/	ratio of water > QDIV_LT and < QDIV_UT that should be diverted to Div_TONZ	999	0 - 1	
X_COORD	NB, IZ	float	/	not used	-999	-	
Y_COORD	NB, IZ	Float	/	not used	-999	-	

2.2 Inputs

2.2.1 Rainfall & snow

At each time step, the model separates the precipitation input into liquid rainfall and snowfall based on air temperature. To account for mixed precipitation events (sleet), a linear transition function is used between an upper and lower temperature threshold.

The model parameters SNOWTRT and RAINTRT define the temperature boundaries for this transition. If the air temperature is below SNOWTRT, all precipitation is assumed to fall as snow. Above the RAINTRT threshold, all precipitation is considered liquid rainfall.

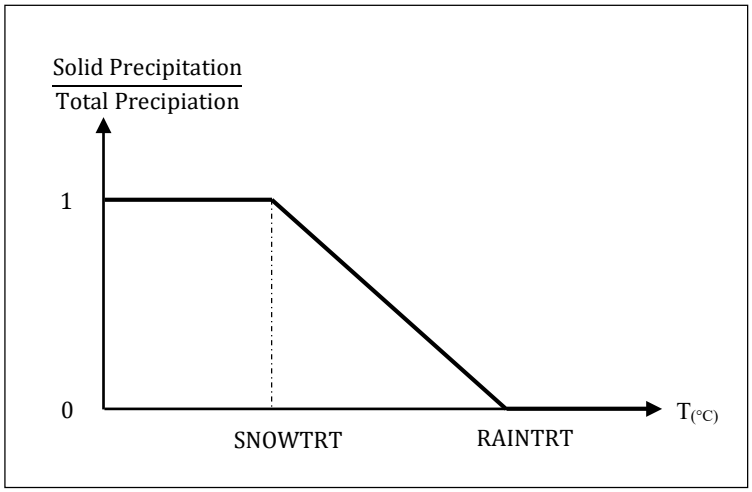


Figure 4. Relationship between solid and liquid precipitation as a function of temperature

For temperatures between the SNOWTRT and RAINTRT parameters, the ratio of snowfall to rainfall is linearly interpolated. This gradual transition avoids sharp distinctions between snow and rain events, more accurately representing the mixed precipitation that can occur within this temperature range (Figure 4).

The equations for the calculation of the different precipitation forms, including multiplicative correction factors for total precipitation (PCOR), liquid precipitation (RAINCOR), and solid precipitation (SNOWCOR), are as follows:

Proportion of liquid and solid precipitation (rainfall and snow), including corrections:

$$PZON_t = P_t * PCOR_{NM} \quad (3)$$

If $T_t > RAINTRT$

$$PRAIN_t = PZON_t * RAINCOR \quad (4)$$

$$PSNOW_t = 0 \quad (5)$$

If $SNOWTRT < T_t < RAINTRT$

$$PRAIN_t = PZON_t * \left(T_t - \frac{SNOWTRT}{RAINTRT - SNOWTRT}\right) \quad (6)$$

$$PSNOW_t = (PZON_t - PRAIN_t) * SNOWCOR \quad (7)$$

$$PRAIN_t = PRAIN_t * RAINCOR \quad (8)$$

If $T_t < SNOWTRT$

$$PRAIN_t = 0 \quad (9)$$

$$PSNOW_t = PZON_t * SNOWCOR \quad (10)$$

T_t	Zonal air temperature (average over time step)	°C
P_t	Zonal precipitation (sum over time step)	mm/dt
$PZON_t$	Corrected precipitation (sum over time step)	mm/dt
$PRAIN_t$	Liquid precipitation / rain	mm/dt
$PSNOW_t$	Solid precipitation / snow	mm/dt
RAINCOR	Correction factor of liquid precipitation to account for systematic errors	-
RAINTRT	Transition temperature, above which precipitation is pure rain	°C
SNOWTRT	Transition temperature, below which precipitation is pure snow	°C
$PCOR_{NM}$	Monthly correction factor for rainfall	-
SNOWCOR	Correction factor of snow to account for systematic errors, e.g., undercatch of snow events	-

2.2.2 Potential evapotranspiration

Climatic processes in the atmosphere determine the upper boundary condition for simulating the soil water balance. The relevant components are precipitation, temperature, radiation, wind, and relative humidity. These climate variables affect potential evapotranspiration (ETP), which is used to estimate actual evapotranspiration in the model.

The potential evapotranspiration is the rate at which evapotranspiration would occur from a large area completely and uniformly covered with growing vegetation that has access to an unlimited supply of soil water, and without advection or heating effects (Dingman 1994, McMahon et al. 2013). The reference evapotranspiration is the amount of water that can be evapotranspired under the prevailing meteorological conditions at optimal water replenishment from a surface with reference vegetation (e.g., grass, 12cm, active growth, full ground cover; Doorenbos and Pruitt (1977)).

The COSERO model uses the Thornthwaite method (Thornthwaite and Mather 1957) to estimate ETP when no other data are provided via an input file. The Thornthwaite method is a temperature-based approach that estimates ETP as a function of mean monthly temperature and a heat index, which is calculated based on the mean monthly temperatures. Other ETP methods have been tested with COSERO (Herrnegger et al. 2012).

The Thornthwaite calculations in COSERO use long-term mean monthly air temperature (parameter TMMON) and actual air temperature, with corrections for latitude-dependent sunshine duration, air saturation during rainfall, systematic errors, and slope and aspect.

$$ETP_t = \left[17.6 * \left(\frac{10 * max(T_t, 0)}{J}\right)^a * f_{geo,NM}\right] * max\left(0, min\left(1.,1 - \frac{PZON_t}{EVPNS}\right)\right) * \text{ETSYSCOR} * \text{ETSLPCOR} \quad (11)$$

$$J = \sum_{Jan}^{Dec} \left(\frac{TMMON_{NM}}{5}\right)^{1.514} \quad (12)$$

$$a = \frac{0.9262}{2.42 - \log(J)} \quad (13)$$

$$ETSLPCOR = (1.605 * 10^{-2} * \sin(\alpha - 90) - 2.5 * 10^{-4}) * \varphi + 1 \quad (14)$$

ETP_t	Potential evapotranspiration	mm/dt
T_t	Mean zonal air temperature	°C
J	Heat index for 12 months	-
a	Variable connected to heat index	-
$TMMON_{NM}$	Model parameter - Mean zonal monthly temperature	°C
$f_{geo,NM}$	Monthly correction factor for sunshine duration depending on latitude given by vector [0.76, 0.80, 1.02, 1.14, 1.31, 1.33, 1.34, 1.23, 1.05, 0.93, 0.77, 0.72] (Bretschneider et al. 1993)	-
$PZON_t$	Corrected precipitation (sum over time step)	mm/dt
EVPNS	Critical precipitation rate at which ETP is zero	mm/dt
ETSYSCOR	Correction factor for systematic errors	-
ETSLPCOR	Correction factor for slope and aspect conditions (“Golf-factor”, Golf (1981))	-
α	Slope aspect relative to North in degrees	°
φ	Mean slope inclination in degrees	°

To account for possible saturation of the atmosphere, which limits evapotranspiration, a correction is implemented, as the temperature-based evapotranspiration model does not consider other atmospheric conditions (e.g., rain or fog). To address this, the model assumes a linear relationship between dry spell periods and periods where the precipitation rate exceeds a specified threshold. The parameter EVPNS, typically set to a value of 0.7 mm/h, represents this precipitation threshold. During periods when the precipitation rate is higher than EVPNS, the model applies a correction to the evapotranspiration calculation to account for the limited ability of the atmosphere to absorb additional moisture, thereby reducing the rate of evapotranspiration.

2.3 Actual evapotranspiration

The actual evapotranspiration (ETA) represents the quantity of water that is evaporated and transpired from the soil and vegetation under natural moisture conditions. This differs from potential evapotranspiration, which represents the maximum possible rate of evapotranspiration when there are no limitations on soil moisture. Actual evaporation refers to the quantity of water that is evaporated directly from an open water surface or the ground. Transpiration is the process by which water is transferred from the vegetation into the atmosphere in the form of vapor. Together, these two components make up the actual evapotranspiration, which can be lower than the potential rate if the available soil moisture is limited and unable to fully satisfy the atmospheric demand.

The actual evapotranspiration in the COSERO model is calculated based on the potential evapotranspiration described above (or given via an input file) and the available water in the interception, snow, and soil storage. The system states can thereby be a limiting factor.

The total actual evapotranspiration is calculated as the sum of different fluxes stemming from different processes:

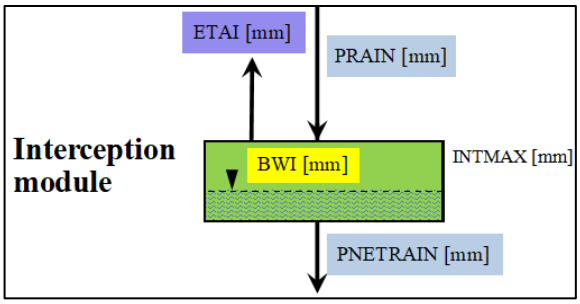
$$ETAT_t = ETAI_t + ETAS_t + ETAG_t \quad (15)$$

$ETAT_t$	Total actual evapotranspiration	mm/dt
$ETAI_t$	Actual evapotranspiration from interception module	mm/dt
$ETAS_t$	Snow sublimation from snow module	mm/dt
$ETAG_t$	Actual evapotranspiration from soil module	mm/dt

Figure 5 presents the calculation of actual evapotranspiration across the different modules, including the relevant model parameters and variables (based on Herrnegger and Nachtnebel (2011)). The modules are presented in the following sections. Note that there is no evapotranspiration (sublimation) from the glacier module.

Figure 5. Schematic overview of the calculation of ETA within the different modules, including relevant model parameters. Note that actual evapotranspiration is also a function of the system states.

2.4 Interception module



Especially in forested catchments, interception is a significant component of the water balance. Interception losses are determined primarily by the duration and intensity of precipitation, as well as by vegetation and climatic factors (Brooks et al. 1997).

The interception is determined by a reservoir with the maximum storage capacity INTMAX. This model parameter is determined by land cover class (Parameter NC) and month (NM) to account for changes in interception over the annual cycle (see Table 9 for the land cover classes defined in COSERO, Table 12 for reclassification of CORINE land use codes to COSERO classes, and Table 10 for standard INTMAX values). A maximum of 50 % of fallen precipitation can be stored in the interception storage, and the rest is throughfall (hardcoded). The content of the interception storage is reduced only by evaporation.

The actual evaporation from the interception module is calculated based on the potential evapotranspiration and Leaf Area Index (LAI) and is limited by the maximum interception storage.

The water that is not held back in the interception storage (BWI) is composed of the 50 % of fallen precipitation that cannot be held back by vegetation and the overflow of the interception storage (PNETRAIN).

$$BWI_t = max\left(0, min\left(INTMAX_{NC,NM}, BWI_{t-1} + 0.5 * PRAIN_t - ETAI_t\right)\right) \quad (16)$$

$$ETAI_t = min\left(\mathrm{INTMAX}_{NC,NM}, ETPINT_t\right) \quad (17)$$

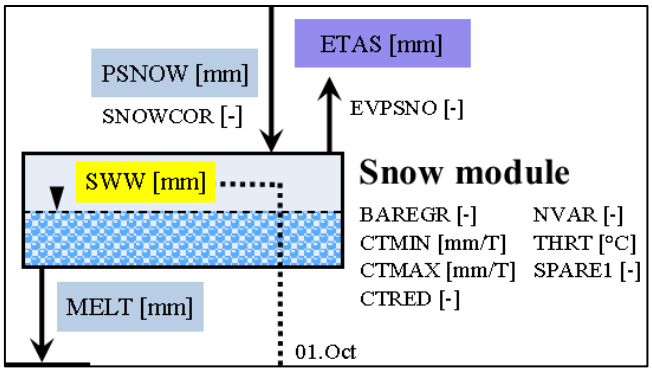
$$ETPINT_t = ETP_t * \frac{\mathrm{LAI}}{\mathrm{LAI} + 1} \quad (18)$$

$$LAI = 1.5 * INTMAX_{NC,NM} \quad (19)$$

$$PNETRAIN_t = 0.5 * PRAIN_t + max\left(BWI_{t-1} - \mathrm{INTMAX}_{NC,NM} + 0.5 * PRAIN_t - ETAI_t, 0\right) \quad (20)$$

BWI_t	Water stored in interception reservoir	mm
$INTMAX_{NC,NM}$	Model parameter - maximum storage capacity of interception storage	mm
LAI	Leaf Ara Index	-
$PRAIN_t$	Liquid precipitation / rain	mm/dt
$ETAI_t$	Actual evapotranspiration from interception storage	mm/dt
$ETPINT_t$	Potential evapotranspiration from interception storage	mm/dt
ETP_t	Potential evapotranspiration	mm/dt
$PNETRAIN_t$	Net-rainfall after interception, reaching the soil module	mm/dt

2.5 Snow module



The processes simulated by the snow module are:

- **Snow accumulation** (accumulation of a snow layer caused by snowfall)
- **Snow melt** (conversion of snow into melt water that may become runoff)
- **Snow sublimation** (liquid to gaseous transition from snowpack to atmosphere)
- **Internal processes** (retention of liquid water, refreezing, changes in the snow density and snow depth)

For understanding the snow module in the source code, it's helpful to know the following:

1. Variables starting with 'k' describe processes and states based on snow classes (where 'k' stands for the German word 'Klassen' meaning 'classes').
2. The snow layer for each snow class is organized in the same way.
3. Variables ending with 'out' describe fluxes leaving the module, while variables ending with 'in' describe fluxes entering the module. The '_B' suffix does not matter in this context.
    - For example, 'KMELTROUT' represents snowmelt leaving the module, and 'KMELTRIN_B' represents snowmelt entering the module (from the previous time step).
4. Global variables used in other COSERO modules have a '_B' suffix, while internal variables do not have any specific ending.
5. Variables ending with 'zon' describe the states of a grid cell.

This chapter of the user's manual is organized in the same way the source code of the snow module is written, with the exception of the description of the snow cover, including the calculation of the snow classes used by COSERO. This is necessary to understand the module more easily.

Model variables describing the snowpack:

KSWIN_B	snow water equivalent of the snowpack	mm SWE
KSHIN_B	Snow depth	mm
KSNOW	New snow	mm
KMELTRIN_B	Retention of liquid water in the snowpack	mm
KMELT	Melt runoff leaving the snowpack	mm
KSWUMIN_B	Snow water equivalent of the snowpack without its liquid water content	mm SWE
SFT	Refrozen water in the snowpack	mm
KETAS	Snow sublimation	mm
NSRHO	Density of new snow	g cm^{-3}
KSRHOIN_B	Density of the snowpack	g cm^{-3}

2.5.1 Description of the snow cover

While the calculations of runoff generation processes in COSERO are carried out on the basis of raster cells or HRUs (hydrological response units), the calculations regarding the snow cover in the model are done on a higher resolution. The reason for this is that snow depth varies greatly in space (see Melvold and Skaugen (2013). Numerous studies have shown that the variability of snow depths on the sub-grid scale can be described by a two parameter log-normal distribution (Pomeroy et al. 1988, Donald et al. 1995). In COSERO, this log-normal distribution (Eq. (21)) is calculated to generate "internal" snow classes, representing sub-grid variability of snow processes within a modeling zone. The mean snow water equivalent of these snow classes represents the mean conditions in the grid cell. The modeler can choose the number of snow classes per cell (IKL) out of a predefined set of numbers: 1 (no log-normal distribution), 2, 3, 5, 7, and 10. IKL is set globally, i.e. for all raster cells in the modelled catchment. In most cases, 5 snow classes are most suitable. A scheme of the snow cover in COSERO, including the snow classes, is shown in Figure 6.

$$SWE_{t,IKL} = e^{\mu+\sigma*\eta} \quad (21)$$

μ and σ are, respectively, the mean and standard deviation of the freshly fallen snow η. Through the variance of η, NVAR, the modeller can manipulate the partitioning of freshly fallen snow into the snow classes. The shape of the distribution is shown in Figure 7. Note that the different values of NVAR on the z-axis are drawn in non-uniform distances.

The log-normal distribution may be interpreted as a statistical description of snow processes taking place on the subgrid scale (Pomeroy et al. 1988), such as accumulation of snow on the lee side of exposed ridges or the influence of elevation differences within a grid cell (Hiemstra et al. 2006). Since equation (21) applies to solid precipitation only, and all subsequent processes regarding the snow cover are applied to each snow class separately, the initial log-normal distribution will vary over time by processes such as melting, refreezing or sublimation of snow.

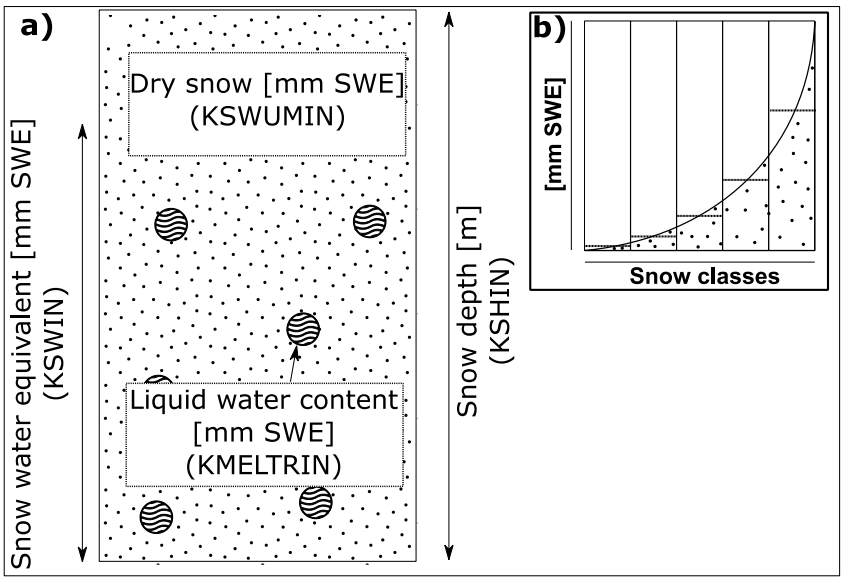


Figure 6. Schematic view of the snow cover in COSERO. (a) Composition of one snow class. (b) View of one grid cell including five snow classes, each of which is composed in the way shown in (a). Snowfall is distributed log-normally throughout the classes (b). Note that the snow depth (KSHIN) is given in meters while all other parameters regarding snow are given in millimeters of snow water equivalent (Frey and Holzmann 2015).

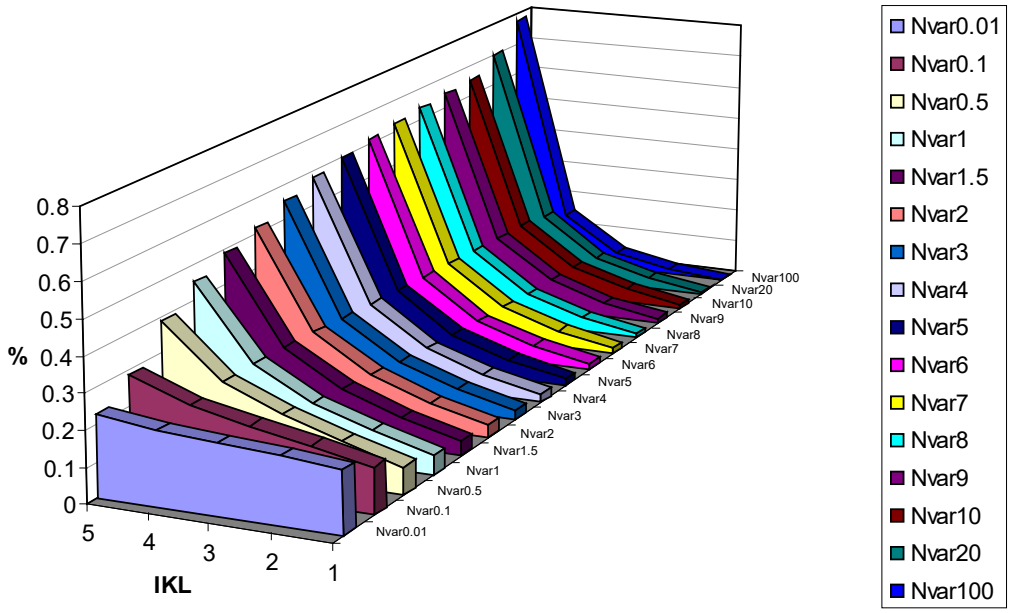


Figure 7. Share of freshly fallen snow assigned to each snow class (total number of snow classes IKL = 5) based on a log-normal distribution as a function of the model parameter NVAR.

2.5.2 Computation of the soil temperature

The temperature of the soil, i.e., the non-snow-covered ground including its canopy, determines if the model allows the creation of a snow cover. At positive temperatures, snow would melt immediately after hitting the ground. The soil's temperature is calculated using Eq. (22).

$$TSOILZON\_B_t = TSOILZON\_B_{t-1} \cdot \frac{1}{(1+W)} + TZON\_B_t \cdot \frac{W}{(1+W)} \quad (22)$$

Where $W = \frac{RDT}{24} \cdot 0.5$.

TSOILZON_B	Soil temperature	°C
TZON_B	Air temperature	°C
RDT	Modeling time step	-

The soil temperature cannot take any value. Its upper and lower boundaries are set by the user (TSOILMAX_, TSOILMIN_). Typically, the maximum value is in the range of 15°C, the lower value in the range of -5°C.

2.5.3 Computation of the reduction of the snow melt factor

COSERO uses a modified temperature-index approach for snow melt modeling and considers the albedo of snow. A high albedo means that a high portion of radiation is reflected, and in consequence, less energy is left and therefore melting is reduced (i.e., the melting factor CT is reduced). Newly fallen snow has a high albedo, and so the melting factor CT is reduced by the factor CTRED (=model parameter). The older the snow gets, the lower its albedo becomes, and melting is increased again (CT becomes higher). However, an old snow cover overlaid by only a little new snow does not affect the albedo of the snow cover as strongly. Thus, a threshold of new

snow (S_{CRIT}) needs to be reached to trigger the full effect of the albedo on the properties of the snow cover regarding its melting behavior. When the threshold of new snow is reached or exceeded, the melting factor is reduced by CTRED. Below the threshold, the reduction factor increases until it reaches one (= albedo drops until the value of the old snow is reached again). The calculation of the reduction factor REDMELTZON (Eqs. (23) and (24)) is shown in Figure 8. The change in REDMELT over time due to new snowfall is shown in Figure 9, and the resulting fluctuation and saw tooth course of the CT curve as a result of the changing albedo of the snow cover is shown in Figure 10.

If $PSNOWZON\_B_t > 0$, REDMELT is calculated based on the reduction factor of the previous day and the amount of fallen snow in the timestep:

$$REDMELT_t = max \begin{cases} CTRED \\ REDMELT_{t-1} - PSNOWZON\_B_t * \dfrac{1 - CTRED}{S_{crit}} \end{cases} \quad (23)$$

If $PSNOWZON\_B_t = 0$, REDMELT is increased again, gradually approaching the value 1:

$$REDMELT_t = min \begin{cases} 1 \\ REDMELT_{t-1} + \dfrac{1 - REDMELT_{t-1}}{S_{crit}} * \dfrac{RDT}{24} \end{cases} \quad (24)$$

$REDMELT_t$	Reduction factor of the CT value	-
CTRED	Model parameter - factor to reduce the melt factor CT after snow fall because of higher albedo	-
PSNOWZON_B	Solid precipitation / snow	mm/dt
S_{CRIT}	Threshold value	mm
RDT	Modeling time step	-

In the present version of COSERO, S_{CRIT} is hardcoded to the value of 5. This value was used in several studies and projects carried out not only using COSERO but also other models, too (Stanzel et al. 2008, Frey and Holzmann 2013, Frey and Holzmann 2015). Note that the albedo is calculated on the basis of the grid cell, not on the basis of snow classes. Also note that the computation of snowfall (PSNOWZON_B) is done in the module p_t_n_B.

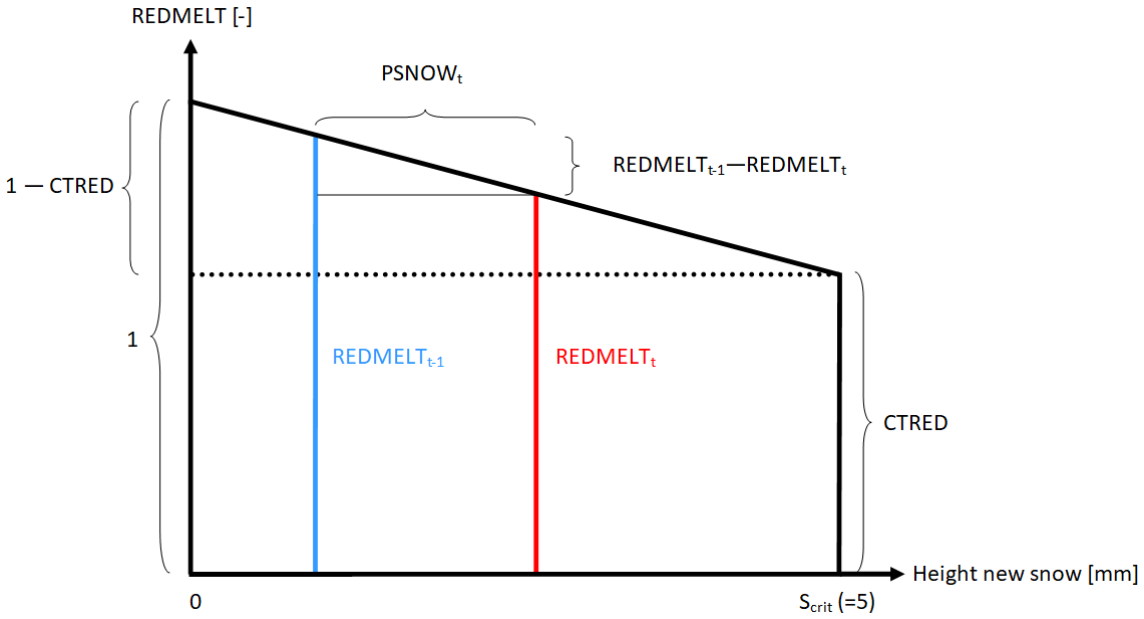


Figure 8. Calculation of REDMELT for PSNOW$_t$ > 0.

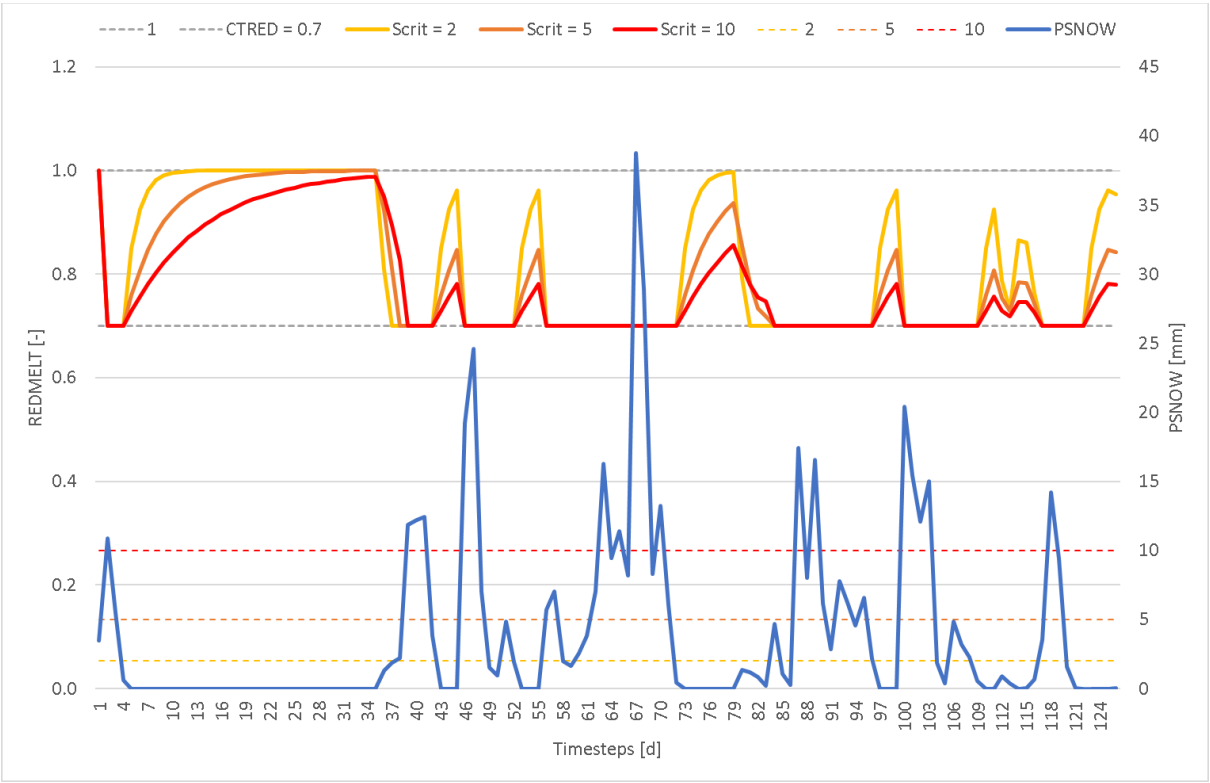


Figure 9. Change of the melt factor reduction factor REDMELT over time, dependent on new snow fall PSNOW. In COSERO, Scrit is hardcoded to 5mm, but here three different REDMELT curves are shown to compare the influence of this threshold (Scrit = 2, 5, 10). REDMELT is constrained by CTRED (here 0.7) and 1 (=no reduction of melt factor).

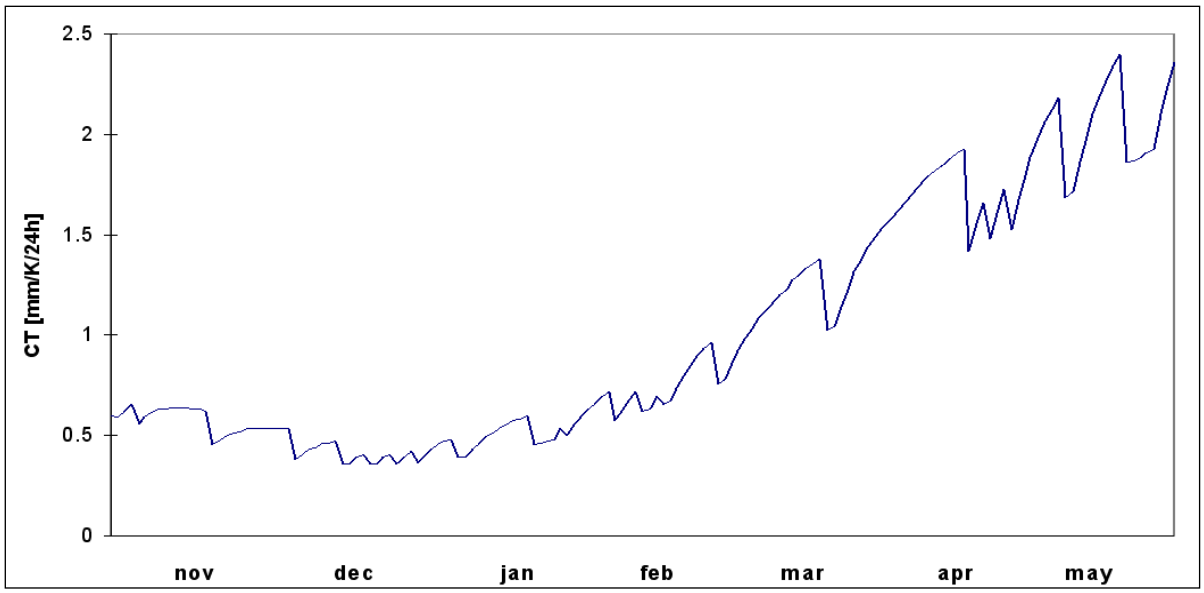


Figure 10. Example of the seasonal variation of the melting factor due to changes in the albedo of the snow cover.

2.5.4 Computation of the potential snow melt factor

The potential snow melt factor CTPZON is also calculated on the basis of grid cells. Since the concept of the temperature-driven approach used in COSERO indirectly accounts for global radiation, the snow melt factor reaches its highest values in the year at the time when the solar radiation reaches its maximum. This is the case on July 21st. The minimum of both the CT value and the global radiation are on December 21st. In between these dates, the potential CT value follows a cosine curve, given by Eq. (25).

$$CTPZON\_B_t = -cos\left(JDAY \cdot \frac{2\pi}{365}\right) \cdot \frac{\mathrm{CTMAX} - \mathrm{CTMIN}}{2} + \frac{\mathrm{CTMAX} + \mathrm{CTMIN}}{2} \quad (25)$$

CTPZON_B_t	Potential snow melt factor	mm °C^{-1}
JDAY	Julian day of the year	-
CTMAX	Maximum value of the snow melt factor on June 21st	mm/°C/d
CTMIN	Minimum value of the snow melt factor on Dec 21st	mm/°C/d

The actual value of CT (CTAZON) is calculated by multiplying the potential value of CT by the correction factor accounting for albedo (REDMELT). This is given by Eq. (26).

$$CTAZON\_B_t = CTPZON\_B_t \cdot \mathrm{REDMELTZON\_B_t} \quad (26)$$

CTAZON_B_t	Actual snow melt factor	mm °C^{-1}
CTPZON_B_t	Potential snow melt factor	mm °C^{-1}
REDMELTZON_B_t	Reduction factor of the CT value	-

CTAZON_B represents the amount of snow water equivalent that can be melted per time step and Kelvin above a threshold that allows for melting. Obviously, if the computed snow class provides less snow than CTAZON_B, only the present snow will be melted (otherwise, the model would produce water).

2.5.5 Checking for water bodies

When snow falls on water bodies like lakes or rivers in COSERO, it is treated as rain rather than accumulating as snow cover. This simplification is used because the model does not simulate the formation of ice layers on water surfaces, even during extended periods of below-freezing temperatures. As a result, any precipitation falling on water bodies is processed as liquid precipitation in the model calculations, regardless of the air temperature.

2.5.6 Is there any snow?

The model checks whether the actual grid cell is covered with snow. Since the model uses the approach of log-normal distributed snow over several snow classes, it is sufficient to check whether the "highest" snow class, i.e., the one holding the most snow, contains any snow. It also checks whether snowfall occurs. If neither is the case, snow modeling is skipped. Otherwise, snow processes are modelled.

2.5.7 Fresh snow density

The model sets the density of newly fallen snow to the maximum new snow density (*NSRHOMAX*, Eq. (27)). The density of the total snowpack is calculated differently. This is described further down in the manual.

$$NSRHO = NSRHOMAX \tag{27}$$

NSRHO	Density of new snow	g cm^{-3}
NSRHOMAX	model parameter – maximum density of newly fallen snow	g cm^{-3}

2.5.8 Statistical description of the temperature field of a grid cell

Similar to the concept of log-normal distributed snow within a grid cell, the air temperature is not equally distributed over a relatively large area, such as 1x1 km, which is often used as a grid cell size in COSERO. To account for that, the value of the air temperature is disaggregated and distributed log-normally using seven (hardcoded) temperature classes. These classes are used only to calculate the potential snow melt produced by the grid cell computed. The parameter for the disaggregation of the temperature field is TVAR. In the standard parameterization, however, this parameter is set to 0, meaning that the temperature field is uniformly distributed. When COSERO is used with high spatial resolution (such as 1x1 km grid cells), assuming a uniform temperature within each model zone is generally reasonable. This is because temperature variations can be assumed to be typically small over such limited spatial extents.

2.5.9 Computation of potential snow melt

Similar to the concept of potential and actual evapotranspiration, potential snow melt describes the amount of snow that is able to melt under the given circumstances. The actual snow melt, of course, is lower.

Snowmelt may be caused by air temperatures above the melting point of water (Eq. (28)) or by relatively warm rainfall (Eq. (29)) that has the ability to melt more snow. The total potential snowmelt SMTPOT is the sum of both processes (Eq. (30)).

If TZON_B > 0:

$$RAINM = PNETRAINZON\_B_t * \frac{4.186}{333.66} * TZON\_B_t \quad (28)$$

If TZON_B > 0 and TZON_B > THRT:

$$TEMPM = TEMPM_{t-1} + \sum_{i=1}^{7} \frac{1}{7} * TEMP\_VAR_i * CTAZON\_B_t * \frac{RDT}{24} \quad (29)$$

$$SMTPOT = RAINM + TEMPM \quad (30)$$

CTAZON_B	Actual snow melt factor	mm °C^{-1}
PNETRAINZON_B	Amount of rainfall	mm/dt
RAINM	Potential snowmelt caused by rain	mm/dt
RDT	Model time step	-
SMTPOT	Potential snow melt	mm/dt
TEMP_VAR	Log-normal distributed air temperature	°C
TEMPM	Potential snowmelt caused by temperature	mm/dt
THRT	Model parameter - threshold temperature above which snow melt is simulated	°C
TZON_B	Air temperature	°C

In Eq. (28), there are two hardcoded parameters. 4.186 is the specific heat of liquid water (kJ/(kg*K)), while 333.66 refers to the enthalpy of fusion of ice (melting energy, kJ/kg). Note that it is assumed that the temperature of rain is the same as the air temperature.

2.5.10 Potential sublimation of snow

Water has the ability to change its state of aggregation not only from liquid to gaseous and liquid to solid, but also from solid to gaseous. This process is called sublimation. Sublimation depends on many properties, for instance the humidity of the air, the air temperature, turbulent fluxes, radiation etc. For more detail see e.g. Bernhardt et al. (2012) or Strasser et al. (2008). In COSERO, sublimation is considered in a very parsimonious way. It is calculated by multiplying the potential evapotranspiration with a (constant) factor (EVPSNO).

$$POTETAS_t = (ETP_t - ETAI_t) * EVPSNO \quad (31)$$

$POTETAS_t$	Potential snow sublimation	mm/dt
ETP_t	Potential evapotranspiration	mm/dt
$ETAI_t$	Actual evapotranspiration from interception storage	mm/dt
EVPSNO	Model parameter - correction factor for snow sublimation	-

Since all potential fluxes are calculated at this time in the model program, the loop over the snow classes begins here. All calculations are done for each snow class separately.

2.5.11 Transition of snow to glacier ice

Any snow that lies on a glacier cell (Land cover class NC=8) on October 1st is transformed into ice. This means ACCGLAC is increased and SWW is set to zero. See Chapter 2.6 for more details regarding the glacier module.

2.5.12 Does snowfall occur?

First, it is checked whether snowfall occurs. If it does, the new snow is added according to the log-normal distribution to the respective snow class. If no snowfall occurs, the internal variables KN and SNOWKL are set to zero. SNOWKL is the internal name of the snow depth (KSHIN_B), and KN is the internal name of the snow water equivalent (KSWIN_B).

2.5.13 Is the computation of snowmelt necessary?

Obviously, if the actual snow class is not covered by snow, computation of snowmelt is not necessary. Note that if the “highest” snow class is not covered by snow, the model would not have entered this loop at all. This is checked by checking if KWSIN_B and SNOWKL are below 0.00001. The reason for not comparing them to 0.0 is that mathematically, there might be snow left in the 10th decimal place, for instance. Then the routine would be executed. The model checks both KWSIN_B (existing snow from the previous time step) and SNOWKL (new snowfall) to determine if any snow is present in the snow class. If both values are zero, indicating no snow cover exists, any precipitation is treated as liquid and added directly to the ground surface through the input variable PRAINSOILZON_B.

2.5.14 Computation of actual snow melt

Eq. (32) is used to calculate actual snow melt (SMT). This value represents how much snow turns into liquid water during a time step. The actual melt equals the potential melt when sufficient snow is available. The model ensures physically meaningful results by preventing negative melt values.

It's important to distinguish between two different processes:

- The melting of snow into liquid water (SMT)
- The release of water from the snowpack (meltwater outflow)

These are different quantities because the snowpack can retain some liquid water (represented by KMELTR). Therefore, not all melted snow immediately leaves the snowpack as runoff. The

KMELTR parameter, which represents this retention capacity, is implemented as a negative flux in the model.

$$SMT = min \begin{cases} \text{SMTPOT} \\ KSWIN\_B - KMELTRIN\_B + SNOWKL \end{cases} \quad (32)$$

SMT	Actual snowmelt	mm/dt
SMTPOT	Potential snow melt	mm/dt
KSWIN	Snow water equivalent of the snowpack	mm
KMELTRIN_B	Retention of liquid water in the snowpack	mm
SNOWKL	New snow	mm/dt

2.5.15 Computation of the actual water holding capacity

The water holding capacity of the snowpack depends on its density. Snow with a low density has a higher water holding capacity, and the larger the density gets, the lower the water holding capacity is. It is calculated using Eq. (33).

$$KAWHCAP = WHCAP\_B - SRHOEND - SRHOMAX\_B * DWHCAP\_B \quad (33)$$

$$SRHOEND = \frac{KSWIN\_B}{\left(\frac{SETCON\_B * \frac{RDT}{24} * \frac{KSWIN\_B}{SRHOMAX\_B} - \frac{KSHIN\_B}{2} + KSHIN\_B}{1 + \frac{SETCON\_B}{2} + \frac{RDT}{24}} \right)} \quad (34)$$

DWHCAP_B	Model parameter – decrease of water holding capacity with increasing snow density	$g^{-1}cm^{-3}$
KAWHCAP	Actual water holding capacity	-
KSHIN_B	Snow depth	mm
KSWIN_B	Snow water equivalent of the snowpack	mm
RDT	Model time step	-
SETCON_B	Settlement time constant	-
SRHOEND	Density of the old snowpack at the end of the time step	$g\ cm^{-3}$
SRHOMAX_B	Model parameter – maximum density of snow layer	$g\ cm^{-3}$
WHCAP_B	Water holding capacity at the maximum snow density	-

2.5.16 Calculation of fluxes inside the snowpack and leaving the snowpack

It is very important to follow the exact sequence in the calculation of the following fluxes, as some are calculated more than once.

LIQU (liquid phase of the snowpack):

$$LIQU = SMT + RAINKL + KMELTRIN\_B \quad (35)$$

SMT (actual melt of snow):

$$SMT = max \begin{cases} 0 \\ SMT + \min(0, KMELTRIN\_B) \end{cases} \quad (36)$$

KETAS (snow sublimation):

$$KETAS = max \begin{cases} 0 \\ \min(POTETAS, KSWUMIN\_B + SNOWKL - SMT) \end{cases} \quad (37)$$

KMELTR (retention of liquid water):

$$KMELTR = max \begin{cases} 0 \\ (KSWUMIN\_B - SMT - KETAS) * KAWHCAP \end{cases} \quad (38)$$

KMELT (runoff caused by snowmelt):

$$KMELT = max \begin{cases} 0 \\ LIQU - KMELTR \end{cases} \quad (39)$$

KMELTR (retention of liquid water, recalculation):

$$KMELTR = min \begin{cases} LIQU \\ KMELTR \end{cases} \quad (40)$$

LIQU	Cold content of the snowpack	mm
KAWHCAP	Actual water holding capacity	-
KETAS	Actual snow sublimation	mm/dt
KMELTR	Retention of liquid water inside the snowpack	mm
KMELT	Melt water leaving the snowpack and becoming runoff	mm/dt
KSWUMIN	Snow water equivalent of the snowpack without its liquid water content	mm
POTETAS	Potential snow sublimation	mm/dt
RAINKL	Rain	mm/dt
SMT	Actual snow melt	mm/dt
SNOWKL	New snow	mm/dt

Since these equations are not necessarily easy to understand, a short description is given in the following. First, the liquid phase of the snowpack is calculated (LIQU). This is done by adding all components of the snowpack that describe liquid water. Since KMELTR is a negative flux, LIQU may become negative, too. In this case, LIQU describes a cold content.

After calculating LIQU, the actual snow melt is updated to account for KMELTR.

Then the actual sublimation of snow is calculated (KETAS). Basically, all that is done here is checking whether there is enough snow available for sublimating. If not, all that is left of the snowpack sublimates.

The retention of liquid water is calculated next (KMELTR). This is done by accounting for the actual water holding capacity (KAWHCAP).

Now, the actual melt that becomes runoff and leaves the snowpack (KMELT) is calculated by simply subtracting the water that is held back in the snowpack (KMELTR) from the amount of liquid water in the snowpack (LIQU).

Finally, a check is performed to determine if the retention of liquid water is greater than the actual amount of liquid water (Eq. (40)). This, obviously, cannot be the case. Otherwise, water would be created.

When all calculations are done, the snow water equivalent at the end of the time step is computed. This is done by Eq. (41).

$$KSWOUT = \max(0, \text{KSWIN\_B} + \text{RAINKL} + \text{SNOWKL} - \text{KMELT} - \text{KETAS}) \quad (41)$$

KETAS	Actual snow sublimation	mm/dt
KMELT	Melt water leaving the snowpack and becoming runoff	mm/dt
KSWIN	Snow water equivalent of the snowpack	mm
KSWOUT	Snow water equivalent at the end of the time step	mm
RAINKL	Rain	mm/dt
SNOWKL	New snow	mm/dt

2.5.17 Refreezing water

Liquid water inside the snowpack has the ability to refreeze again if the temperature allows for it. This is implemented using Eq. (42), which is basically a description of a negative day-degree method. Refreezing is only calculated for air temperature values below 0 °C.

$$STF = CTNEG_B * TZON_{B_t} * (-1) * \frac{RDT}{24} \quad (42)$$

SFT	Refrozen retained melt water	mm
CTNEG_B	Model parameter – Refreezing factor	mm °C^{-1}
TZON	Air temperature	°C
RDT	Model time step	-

2.5.18 Heat loss of the snowpack

While COSERO includes code to simulate heat loss from the snowpack, this feature is not currently operational in the recommended model setup. The relevant code section contains undocumented hard-coded values and lacks clear explanation of the underlying processes. Test simulations have not shown any discernible impact from this code block on model results. Therefore, it is recommended to disable this feature by commenting out this section of code until proper documentation and testing is implemented.

2.5.19 Update the amount of liquid water in the snowpack

Since the amount of refrozen water has been calculated, the amount of retained liquid water might have been changed since the last calculation. Therefore, it needs to be recalculated by simply subtracting the amount of refrozen water (SFT) from the amount of retained liquid water in the snowpack (KMELTR). In addition, the snow water equivalent of the snowpack without its liquid water content is calculated (KSWUMOUT).

$$KMELTROUT = KMELTR - SFT \quad (43)$$

$$KSWUMOUT = KSWOUT - \max(0, KMELTROUT) \quad (44)$$

KMELTR	Retention of liquid water in the snowpack	mm
KMELTROUT	Liquid water content of the snowpack at the end of the time step	mm
KSWUMOUT	Snow water equivalent of the snowpack without its liquid water content at the end of the time step	mm
KSWOUT	Snow water equivalent of the snowpack including its liquid water content at the end of the time step	mm
SFT	Refrozen water in the snowpack	mm

2.5.20 Computation of new snow density, snow depth, and coverage

The properties of the snowpack at the end of the time step are calculated using Equ. (45) to (48). The density of the snowpack is not dependent on temperature but only on time.

$$KSHOUT = \frac{SETCON\_B * \frac{RDT}{24} * \left(\frac{KSWUMIN\_B}{SRHOMAX\_B} - \frac{KSHIN\_B}{2}\right) + KSHIN\_B}{1 + \frac{SETCON\_B}{2} * \frac{RDT}{24}} \quad (45)$$

$$KSRHOOUT = \begin{cases} \frac{KSWUMIN\_B + SNOWKL}{KSHOUT + KN}, & \text{KSWUMIN\_B} > 0 \\ \frac{KSWIN\_B + SNOWKL}{KSHOUT + KN}, & \text{KSWUMIN\_B} \leq 0 \end{cases} \quad (46)$$

$$KSHOUT = KSHOUT + KN - \frac{SMT}{KSRHOOUT} \quad (47)$$

$$KN = \frac{SNOWKL}{NSRHO} \quad (48)$$

KN	Internal name of the snow water equivalent	-
KSHIN_B	Snow depth	mm*
KSHOUT	Snow depth at the end of the time step	mm
KSRHOOUT	Snow density of the snowpack at the end of the time step	mm
KSWIN_B	Snow water equivalent of the snowpack	mm
KSWUMIN_B	Snow water equivalent of the snowpack without its liquid water content	mm
NSRHO	Density of new snow	g cm^{-3}
SETCON_B	Model parameter – settlement time constant	-
SMT	Actual snow melt	mm/dt
SNOWKL	New snow	mm/dt
SRHOMAX_B	Maximum density of snow	g cm^{-3}
RDT	Model time step	-

* Note the difference in mm snow depth and mm water equivalent!

2.5.21 Computation of the zone values

The snow melt and the properties of the snowpack are calculated for each of the snow classes by that time in the program code. COSERO, in general, needs values for snow coverage and meltwater per zone (in most cases, zones are equal to grid cells). Therefore, the properties of each snow class have to be aggregated to match these requirements. This is done by averaging the class values for the respective flux for each grid cell as given by Eqs. (49) to (56).

$$MELTZON\_B = MELTZON\_B + \frac{KMELT}{IKL} * (1 - BAREGR\_B) \quad (49)$$

$$SWWZON\_B = SWWZON\_B + \frac{KSWOUT}{IKL} * (1 - BAREGR\_B) \quad (50)$$

$$ETASZON\_B = ETASZON\_B + \frac{KETAS}{IKL} * (1 - BAREGR\_B) \quad (51)$$

$$AWHCAPZON\_B = AWHCAPZON\_B + \frac{KAWHCAP}{IKL} * (1 - BAREGR\_B) \quad (52)$$

$$MELTRZON\_B = MELTRZON\_B + \frac{KMELTROUT}{IKL} * (1 - BAREGR\_B) \quad (53)$$

$$SHZON\_B = SHZON\_B + \frac{KSHOUT}{IKL} * (1 - BAREGR\_B) \quad (54)$$

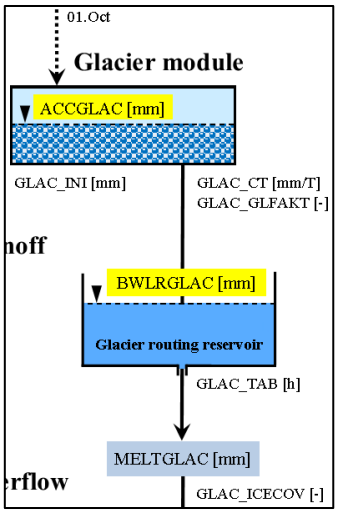
$$SRHOZON\_B = SRHOZON\_B + \frac{KSRHOOUT}{IKL} * (1 - BAREGR\_B) \quad (55)$$

$$SCOVZON\_B = SCOVZON\_B + \frac{KSCOV}{IKL} * (1 - BAREGR\_B) \quad (56)$$

AWHCAPZON_B	Water holding capacity of the snowpack	mm
BAREGR_B	Model parameter – fraction of ground that is never snow covered	-
ETASZON_B	Sublimation of snow	mm/dt
IKL	Number of snow classes used	-
MELTRZON_B	Retention of liquid water in the snowpack	mm
MELTZON_B	Snowmelt	mm/dt
KAWHCAP	Actual water holding capacity	-
KETAS	Actual snow sublimation	mm/dt
KMELT	Melt water leaving the snowpack and becoming runoff	mm/dt
KMELTROUT	Liquid water content of the snowpack at the end of the time step	mm
KSCOV	Fraction of zone covered by snow at the end of the time step	-
KSHOUT	Snow depth at the end of the time step	mm
KSRHOOUT	Snow density of the snowpack at the end of the time step	g cm^{-1}
KSWOUT	Snow water equivalent of the snowpack including its liquid water content at the end of the time step	mm
SCOVZON_B	Fraction of zone covered by snow	-
SHZON_B	Snow depth	mm
SRHOZON_B	Snow density	g cm^{-1}
SWWZON_B	Snow water equivalent	mm

At the end of this module, all internal variables describing the properties of the snow classes are saved to global variables. When the model enters the snow module the next time for that grid cell, i.e., in the next time step, it reads the values from the global variables again.

2.6 Glacier module



The processes simulated in the parsimonious glacier model are:

- **Transformation of snow to ice** (snow that still lies on the glacierized area on October 1st is transformed into ice)
- **Ice melt** (conversion of ice into melt water)
- **Routing** of melt water by means of a linear reservoir

Note that there is no evapotranspiration or sublimation from the glacier module.

Parameters used in this module:

GLAC_CT	Factor to adjust snow melt factor for glacier melt	-
GLAC_GLFAKT	Radiation index	-
GLAC_ICECOV	Fraction of zone covered by glacier	-
GLAC_TAB	Recession constant for simulating routing within a glacier	h
GLAC_INI	Initial glacier water equivalent	mm

The processes surrounding glacier accumulation and ablation are shown in Figure 11. Glacier melt occurs only when the snow cover has completely melted. Then the meteorological variables, temperature and radiation, become the governing influences. Therefore, a direct coupling with the snow module to determine the current snow cover is necessary.

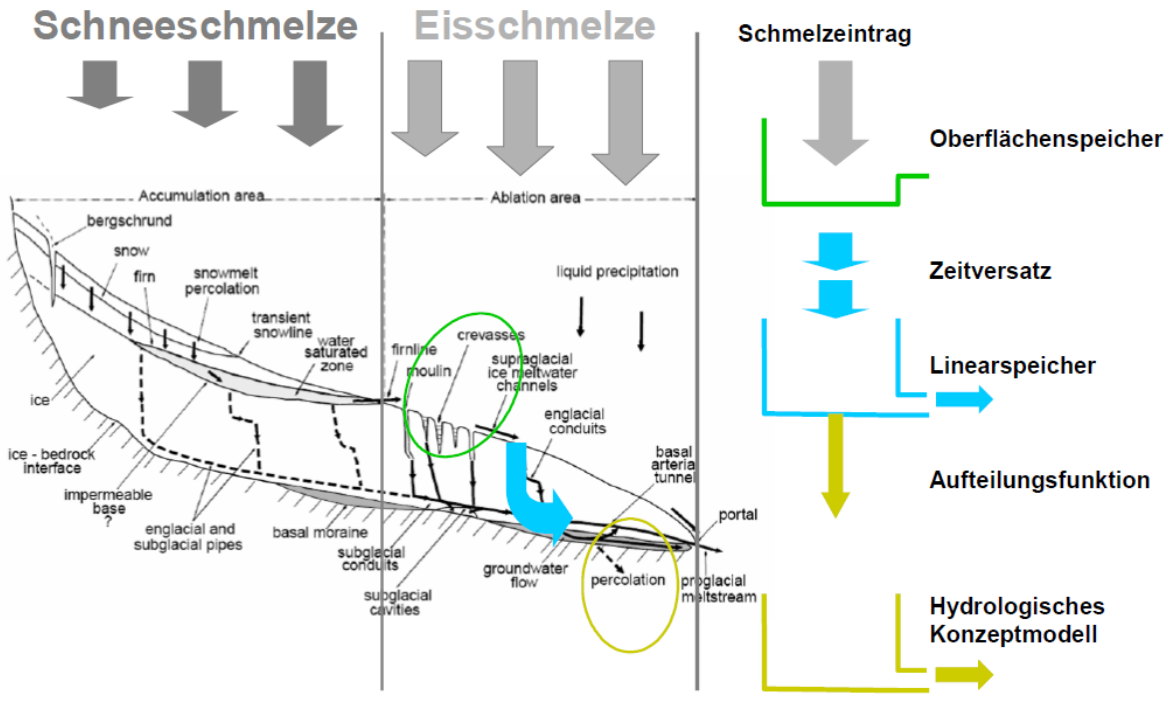


Figure 11. Conceptual melting processes of snow and ice.

In contrast to the snow module, internal transport processes of the melt water such as surface retention in crevasses or glacier lakes, retention in glacier streams or hollows, or infiltration into porous moraine-substrate are not separately described. Only melt water routing within the zone is considered with a linear reservoir model and the recession constant GLAC_TAB.

Glacier melt is calculated based on either a temperature-index method or a combined temperature / radiation method by Hock (1999). The following chapters describe the glacier processes in the same order as they are carried out in the source code.

2.6.1 Is the cell glacierized?

If the land-use of the zone is not defined as glacier (NC = 8), then the glacier module is skipped.

2.6.2 Initial thickness of the ice layer

The parameter GLAC_INI represents the initial ice volume at the beginning of the simulation, expressed as mm water equivalent, from which ice will melt and accumulate. This information could be derived from distributed ice thickness data, or set to an "infinite" glacier by assigning very high values to GLAC_INI (e.g., 99999).

2.6.3 Conversion of snow into ice

Snow that still lies on the glacierized area on October 1st is transformed into ice. The following equations describe the accumulation of ice (ACCGLAC) and the subsequent reduction of the snow water equivalent (SWW). Since the reduction of the snow cover leads to high amounts of glacier melting due to a decrease in the Albedo (see Eq. (65)), only 95 % of the snow cover (snow water equivalent) is converted into ice, and 5 % remains.

$$ACCGLAC = ACCGLAC + 0.95 * SWWZON \quad (57)$$

$$SWWZON = 0.05 * SWWZON \quad (58)$$

ACCGLAC	Glacier ice water equivalent	mm
SWWZON	Snow water equivalent	mm

2.6.4 Glacier melt

Ice melt occurs only when there is no snow cover, and the air temperature is above the threshold temperature used to simulate snow melt (THRT). Then the melt process is governed by meteorological conditions. In this case, there are two different methods to choose from. First, a classic temperature-index method (Eq. (59)) where melting is only driven by air temperature. The second is based on a combined method by Hock (1999) (Eq. (60)), which also incorporates global radiation into the melting process.

$$MELTGLAC_t = CTA_t * GLAC\_CT * T_t * (1 - SCOV_t) \quad (59)$$

$$MELTGLAC_t = \left(CTA_t * GLAC\_CT + GLAC\_GLFAKT * rad_{NM,NHOUR}\right) * T_t * (1 - SCOV_t) \quad (60)$$

$MELTGLAC_t$	Glacier melt	mm/dt
CTA_t	Snow melt factor from snow module considering Albedo dynamics	mm/°C/dt
GLAC_CT	Factor to adjust snow melt factor for glacier	-

GLAC_GLFAKT	Radiation modulation factor	m^2/W*
$rad_{NM,NHOUR}$	Reference radiation (diurnal pattern per month)	W/m^2
T_t	Air temperature	°C
$SCOV_t$	Snow cover rate	-

* unit adapted to consider final output units

The combined method is the standard method implemented in the code (meltmethod = 4). The reference radiation is based on the long-term average global radiation measured at the Sonnblick Observatory on Mt. Hoher Sonnblick. They are provided in the file radmat.par and can be seen in Figure 12, where the seasonality is clearly visible.

The temperature and radiation indices are related to daily values, but COSERO automatically adjusts them if a different time discretization is used, so no manual adjustments are necessary.

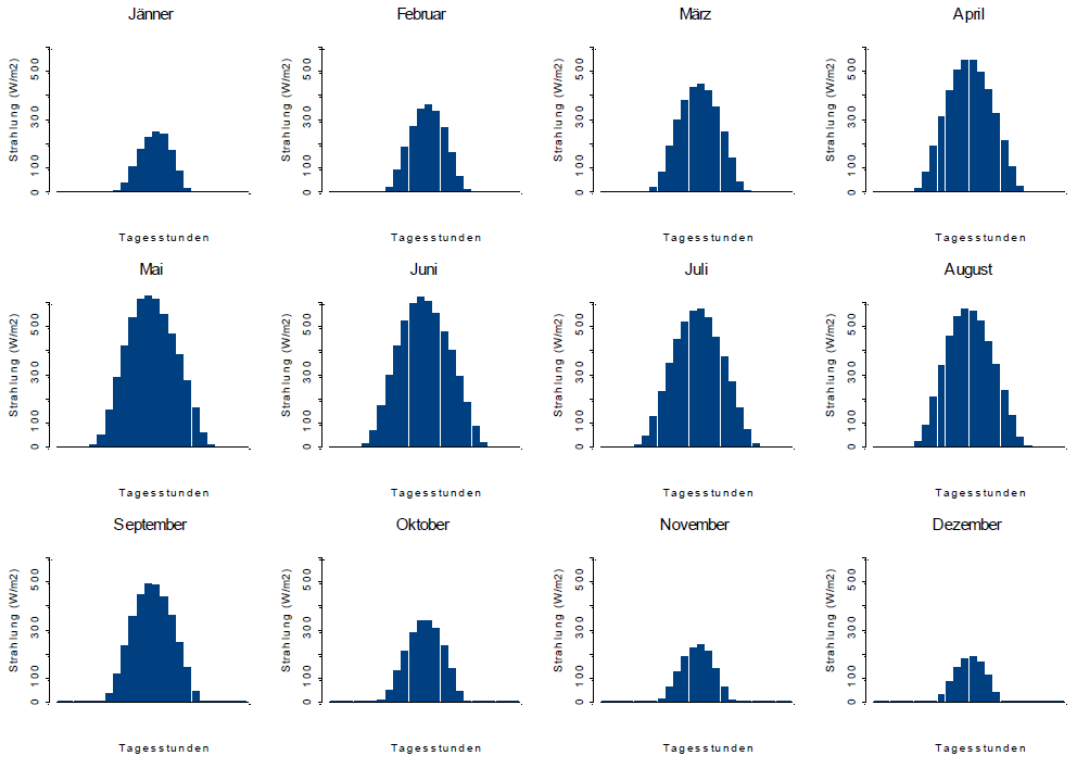


Figure 12. Diurnal variation of global radiation per month at Mt. Hoher Sonnblick (via Nachtnebel et al. (2009a)).

2.6.5 Routing of glacier melt

If the glacier recession constant GLAC_TAB is above 0.00001, then the melt water is routed with a linear reservoir model with the storage BWLRGLAC and the recession constant GLAC_TAB. However, this storage is currently hardcoded to zero, so no buffering of the melt water is conducted.

Up to this step, the model assumes that the whole zone is glacierized, which may not always be the case and can be defined for each cell with GLAC_ICECOV. In a final step, the routed melt water is multiplied by this factor.

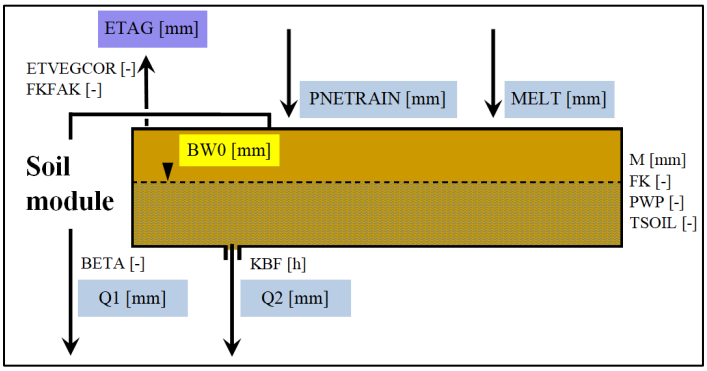
The glacier melt (MELTGLAC) is added to the total zone runoff along with the runoff from the other modules.

2.7 Soil module

The following processes are simulated in the soil module:

- **Evapotranspiration** (flux ETAG)
- **Fast** (surface) **runoff** (flux Q1)
- **Percolation** (flux Q2)

All the following equations are calculated for every zone in the subbasin.



2.7.1 Water balance of soil module

$$BW0_t = BW0_{t-1} + QZU_t - ETAG_t - Q1_t - Q2_t \quad (61)$$

$BW0_t$	Water stored in soil module	mm
QZU_t	Total inflow to soil module: Rainfall plus snowmelt	mm/dt
$ETAG_t$	Actual evapotranspiration from soil	mm/dt
$Q1_t$	Fast runoff from soil module	mm/dt
$Q2_t$	Percolation from soil module	mm/dt

2.7.2 Inflow to soil module

$$QZU_t = MELT_t + PNETRAIN_t * (1 - SCOV_t) \quad (62)$$

QZU_t	Total inflow to soil module: Rainfall plus snowmelt	mm/dt
$PNETRAIN_t$	Rain reaching the soil module	mm/dt
$MELT_t$	Total melt from snow module	mm/dt
$SCOV_t$	Snow cover rate	-

2.7.3 Actual Evapotranspiration from soil

The actual evapotranspiration from snow-free soil is calculated by multiplying the residual potential evapotranspiration ($ETPR_t$) by the factor BFALF.

The residual potential evapotranspiration $ETPR_t$ is the share of ETP that does not come from the interception ($ETAI_t$) or snow module ($ETAS_t$) and has been multiplied by the factor $ETVEGCOR_{NC,NM}$. This correction factor accounts for different vegetation types and seasons. It is dependent on the land cover class (NC) and the month. Examples can be seen in the annex (Table 11).

Note that ETPR is used throughout the model to describe the changing available potential ET as COSERO runs through the modules for interception, snow, and soil, and may have different definitions at different stages.

BFALF describes which fraction of the potential evapotranspiration actually evaporates from the soil and is a function of soil moisture and the model parameters PWP, FK, and FKFAK. FKFAK describes down to which soil moisture ETA equals ETP (see Figure 13). As can be seen in Eq. (65),

an inverse relationship between BFALF and FKFAK leads to higher actual evapotranspiration if FKFAK is lower.

$$ETPR_t = (ETP_t - ETAI_t - ETAS_t) * ETVEGCOR_{NC,NM} \quad (63)$$

$$ETAG_t = BFALF * ETPR_t * (1 - SCOV_t) \quad (64)$$

$$BFALF = \max\left(0, \min\left(\frac{BW0_{t-1} - BW0MIN}{FKFAK * BW0MAX - BW0MIN}, 1\right)\right) \quad (65)$$

$$BW0MIN = PWP * M \quad (66)$$

$$BW0MAX = FK * M \quad (67)$$

$ETAG_t$	Actual evapotranspiration from soil	mm/dt
BW0	Water stored in soil module	mm
BW0MIN	Water stored in soil module at wilting point	mm
BW0MAX	Water stored in soil module at field capacity	mm
M	Model parameter - storage capacity of the soil	mm
PWP	Model parameter - permanent wilting point	-
FK	Model parameter – field capacity	-
FKFAK	Model parameter – factor to compute ETA from ETP as a function of soil moisture	mm/dt
ETP_t	Potential evapotranspiration	mm/dt
$ETPR_t$	Residual potential evapotranspiration after interception and sublimation	mm/dt
$ETAI_t$	Actual evapotranspiration from interception storage	mm/dt
$ETAS_t$	Snow sublimation	mm/dt
$ETVEGCOR_{NC,NM}$	Model parameter – correction factor for potential evapotranspiration to account for vegetation / land use type	-
BFALF	Factor to compute ETA from ETP. Function of soil moisture, PWP, FK, FKFAK	-
$SCOV_t$	Snow cover rate	-

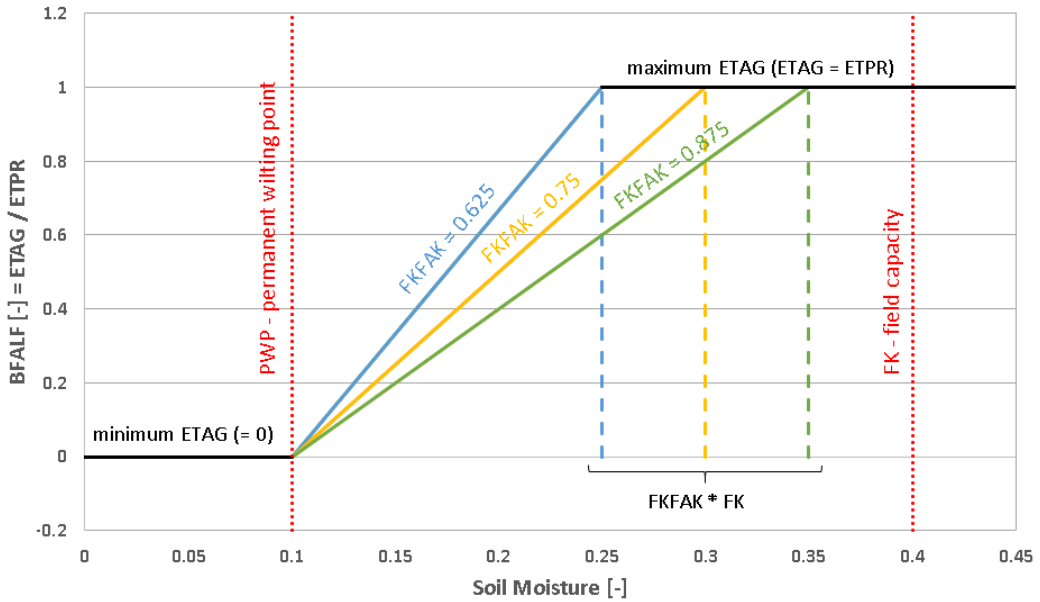


Figure 13. Determination of BFALF as a function of soil moisture, permanent wilting point (PWP), field capacity (FK) and model parameter FKFAK (see Equ. (65)).

2.7.4 Soil temperature $TSOIL_t$ (calculated in snow module)

$$TSOIL_t = \min\left[\max\left(TSOIL_{t-1} * \frac{1}{1+w} + T_t * \frac{w}{1+w}, TSOILMIN\right), TSOILMAX\right] \quad (68)$$

Where $w = \frac{RDT}{24*2}$.

T_t	Air temperature	°C
$TSOIL_t$	Soil temperature	°C
TSOILMIN	Model parameter – minimum soil temperature	°C
TSOILMAX	Model parameter – maximum soil temperature	°C
w	Weighting factor	-
RDT	Model time step	-

2.7.5 Correction of $ETAG_t$ for snow sublimation (for TSOIL < 0)

If the soil is frozen (soil temperature below zero), then the actual evapotranspiration from the soil is reduced by the parameter EVPSNO (treated as snow sublimation).

$$ETAG_t = ETAG_t * EVPSNO \quad (69)$$

$ETAG_t$	Actual evapotranspiration from soil	mm/dt
EVPSNO	Model parameter - correction factor for snow sublimation	-

2.7.6 Fast runoff from soil module

The surface runoff from the soil module is calculated as a non-linear function of soil moisture and the parameter BETA. As can be seen in Figure 14, high BETA values mean the soil retains water for longer, and hardly any surface runoff is generated until higher levels of water storage in the soil are reached. Vice versa, a low BETA value leads to quicker surface runoff generation and little retention of water in the soil. The relative soil moisture content (i.e., the ratio of BW0 to BW0MAX) is referred to as BF in the model output files.

$$Q1_t = PSOIL_t * \left(\frac{BW0_{t-1}}{BW0MAX}\right)^{BETA} \quad (70)$$

$Q1_t$	Fast runoff from soil module	mm/dt
$PSOIL_t$	Total inflow to soil module	mm/dt
BW0	Water stored in soil module	mm
BW0MAX	Water stored in soil module at field capacity (=M * FK)	mm
M	Model parameter – storage capacity of the soil	mm
FK	Model parameter – field capacity	-
BETA	Model parameter – parameter for non-linear runoff generation as a function of soil moisture (see Figure 14)	-

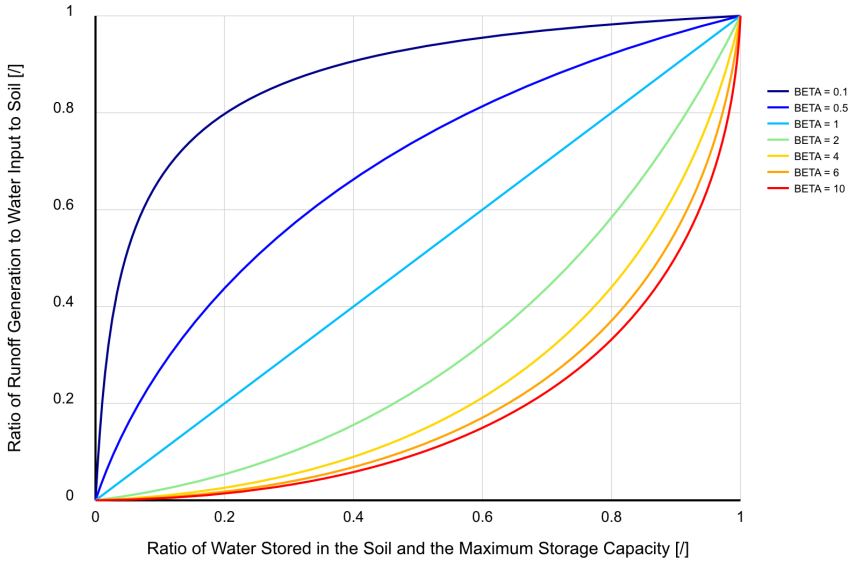


Figure 14. Approximation of the runoff generation as a function of soil moisture and the exponent parameter BETA.

2.7.7 Percolation from soil module (if TSOIL > 0°C)

Percolation only occurs if the soil temperature is above zero. Q2 is calculated with a linear reservoir model with the recession constant KBF. The water stored in the soil that is not bound to the soil matrix (BW0MIN) flows out of the soil module with the following e-function:

$$Q2_t = (BW0_{t-1} - BW0MIN) * (1 - e^{-\frac{RDT}{KBF}}) \quad (71)$$

$Q2_t$	Percolation from soil module	mm/dt
BW0	Water stored in soil module	mm
BW0MIN	Water stored in soil module at wilting point (=M * PWP)	mm
RDT	Model time step	-
KBF	Model parameter – recession constant	h

2.7.8 Total outflow from soil module

$$QVS0_t = Q1_t + Q2_t \quad (72)$$

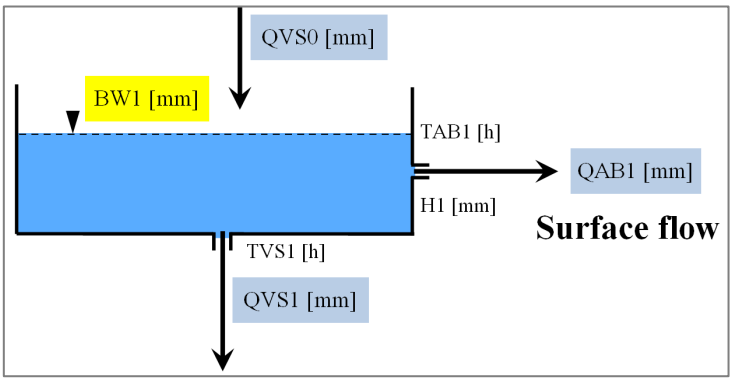
$QVS0_t$	Total outflow from soil module	mm/dt
$Q1_t$	Fast runoff from soil module	mm/dt
$Q2_t$	Percolation from soil module	mm/dt

2.8 (Non-) Linear reservoirs

The following (differential) equations describe the (non-) linear reservoirs. The actual model code uses an analytical solution of the differential equations. It accounts for changes in system states, where threshold values (model parameters H1 and H2) can lead to a falling dry of the outlets at H1 or H2 within a time step (then QAB1, QAB2 equal zero). An internal time step discretization (T1, T2) is included in the code to guarantee that the transition between system states above and below the threshold value is solved exactly.

2.8.1 Surface flow

The subroutine represents the surface-flow module and consists of a linear reservoir with two outlets (surface flow and percolation). An exact analytical solution is used to solve the differential equations. All equations of the surface flow reservoir are calculated for every zone in the subbasin. See run_sfflow_B.f.



Parameters used in this module:

TAB1	Recession constant for surface flow	h
H1	Outlet level of reservoir for simulating surface flow	mm
TVS1	Recession constant for percolation from surface runoff reservoir	h

Variables in this module:

QVS0	Inflow to surface flow reservoir from soil module	mm/dt
BW1	Water stored in surface flow reservoir	mm
QAB1	Surface flow	mm/dt
QVS1	Percolation to interflow reservoir	mm/dt

If the cell represents a waterbody (WATERBODY = 1), the modeling of the reservoir is skipped and the entire inflow from the soil module (QVS0) is used as surface flow (QAB1 = QVS0).

If the model parameter TVS1 is set to zero, then the modeling of the reservoir is also skipped. Surface flow (QAB1) is set to zero and QVS0 goes straight to the interflow module (QVS1 = QVS0).

Depending on whether the initial water level of the reservoir ($BW1_{t-1}$) is above or below the threshold value H1, different equations are used to calculate QAB1 and QVS1. If necessary, the model time-step is split into two parts T1 and T2, with different states (water level above or below the outlet height H1).

Water balance of surface runoff reservoir

$$BW1_t = BW1_{t-1} + QVS0_t - QAB1_t - QVS1_t \quad (73)$$

Fast / surface runoff

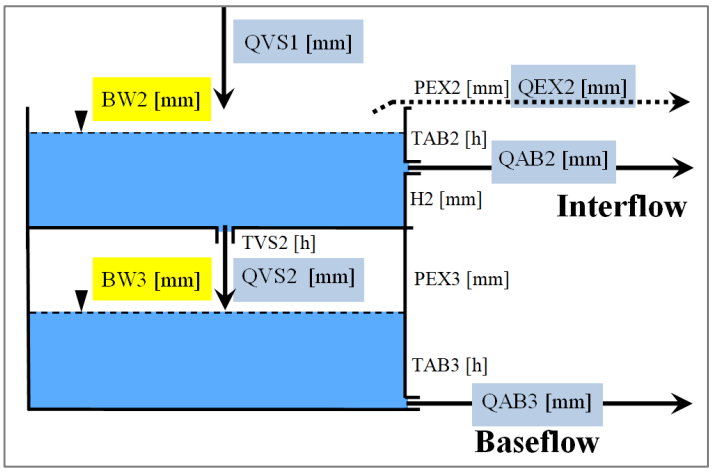
$$QAB1_t = \int_0^t \frac{BW1(t) - H1}{TAB1} dt \quad (74)$$

Percolation from surface flow reservoir to interflow reservoir

$$QVS1_t = \int_0^t \frac{BW1(t)}{TVS1} dt \quad (75)$$

$BW1_t$	Water stored in surface flow reservoir	mm
$QVS0_t$	Inflow to surface flow reservoir from soil module	mm/dt
$QAB1_t$	Lateral outflow (fast / surface runoff)	mm/dt
$QVS1_t$	Percolation to interflow reservoir	mm/dt
TAB1	Model parameter – recession constant for simulating surface flow	h
TVS1	Model parameter – recession constant for percolation from surface runoff reservoir	h
H1	Model parameter – outlet level of reservoir for simulating surface flow	mm

2.8.2 Interflow and baseflow



Interflow and baseflow are computed simultaneously with two coupled linear reservoirs with limited storage capacity (PEX2 and PEX3). An exact analytical solution is used to solve the differential equations. All equations of the interflow and baseflow reservoirs are calculated for every zone in the subbasin. See run_ingwflow_B.f.

Parameters used in this module:

TAB2	Recession constant for interflow	h
TVS2	Recession constant for percolation from interflow to baseflow reservoir	h
H2	Outlet level of reservoir for simulating interflow	mm
PEX2	Storage capacity of interflow reservoir	mm
TAB3	Recession constant for baseflow	h
PEX3	Storage capacity of baseflow reservoir	mm

Variables of this module:

QVS1	Inflow to interflow reservoir from surface flow reservoir	mm/dt
TSOIL	Soil temperature	°C
BW2	Water stored in interflow reservoir	mm
QAB2	Interflow	mm/dt
QVS2	Percolation from interflow to baseflow reservoir	mm/dt
QEX2	Excess runoff when interflow reservoir is full	mm/dt
BW3	Water stored in baseflow reservoir	mm
QAB3	Baseflow	mm/dt

Since there is no percolation from the surface runoff modules (QVS1) if the cell represents a waterbody (WATERBODY = 1), the same applies to the inter- and baseflow module: If the cell is a waterbody, the modeling of the reservoirs is skipped, i.e., COSERO does not consider percolation from lakes.

If the ground is frozen (TSOIL < 0), percolation is greatly reduced. This is accounted for by increasing the recession constant for percolation from the interflow reservoir (TVS2) by a factor of 1000.

If TVS2 is zero, there is no storage in the interflow reservoir, and the water flows directly into the baseflow reservoir (only one reservoir is considered). In this case, the subroutine limgwflow is called, which represents a groundwater reservoir with limited storage capacity. If the baseflow reservoir overtops, excess runoff QEX2 is generated.

Otherwise, the coupled inter- and baseflow are simulated. Since there are two coupled reservoirs (not just one, as in the surface runoff module), there are six distinct state-variable combinations. Each case has its own set of equations for calculating the different variables.

Case 1	BW2 <= H2	and	BW3 < PEX3
Case 2	H2 < BW2 < PEX2	and	BW3 < PEX3
Case 3	BW2 = PEX2	and	BW3 < PEX3
Case 4	BW2 <= H2	and	BW3 = PEX3
Case 5	H2 < BW2 < PEX2	and	BW3 = PEX3
Case 6	BW2 = PEX2	and	BW3 = PEX3

Water balance of interflow reservoir:

$$BW2_t = BW2_{t-1} + QVS1_t - QAB2_t - QVS2_t \quad (76)$$

Interflow:

$$QAB2_t = \int_0^t \frac{BW2(t) - H2}{TAB2} dt \quad (77)$$

Percolation from interflow reservoir to baseflow reservoir:

$$QVS2_t = \int_0^t \frac{BW2(t)}{TVS2} dt \quad (78)$$

BW2	Water stored in interflow reservoir	mm
QVS1	Inflow to interflow reservoir from surface flow reservoir	mm/dt
QAB2	Lateral outflow (interflow)	mm/dt
QVS2	Vertical outflow (percolation from interflow to baseflow reservoir)	mm/dt
TAB2	Model parameter – recession constant for simulating interflow	h
TVS2	Model parameter – recession constant for percolation from interflow reservoir	h
H2	Model parameter – outlet level of interflow reservoir	mm

Water balance of base flow reservoir:

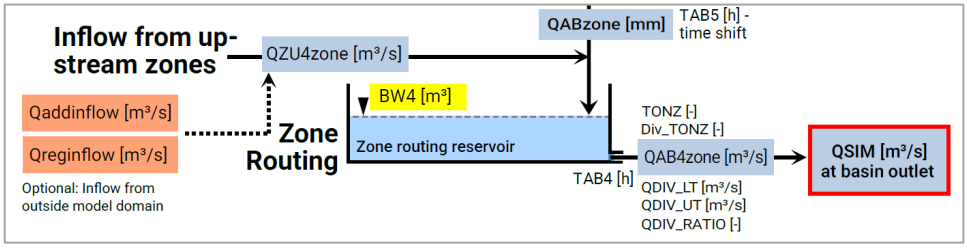
$$BW3_t = BW3_{t-1} + \sum_{IZ=1}^{IZONE} QVS2_{t,IZ} - QAB3_t \quad (79)$$

Base flow:

$$QAB3_t = \int_0^t \frac{BW3(t)}{TAB3} dt \quad (80)$$

$BW3_t$	Water stored in base flow reservoir	mm
$QVS2_{t,IZ}$	Inflow from interflow reservoir from zone IZ	mm/dt
IZONE	Total number of zones within subbasin	-
IZ	Index of zone within subbasin	
$QAB3_t$	Lateral outflow (base flow)	mm/dt
TAB3	Model parameter – recession constant for base flow	h

2.8.3 Zone routing



All equations of the zone routing reservoir are calculated for every zone in the subbasin. Each zone receives as input (i) the local runoff of the zone (QABZON), and (ii) the routed runoff of all upstream zones (QZU4ZON), which may include external inflow from outside the modeling domain provided either directly via an input file (Qaddinflow), or internally calculated via linear regression from an upstream basin's runoff (Qreginflow). A closer description of the external inflow can be found in Chapter 2.9, and the required input structure in Chapters 3.1.5 and 3.1.6.

Runoff is also passed from zone to zone between subbasins. A simple linear reservoir is used for routing, resulting in a cascade of reservoirs for routing throughout the subbasin/basin. See run_sbroute_T.f

If TAB4 is set to zero, the routing reservoir is not considered and the water flows straight to the outlet. Note that units are transformed from [mm] to [m^3/s] and vice versa when necessary, but this is not always explicitly shown in each equation.

Parameters used in this module:

TAB4	Recession parameter for zone routing	h
TAB5	Time shift for QABZONE	h

Variables of this module:

QABZON	Local runoff generated by zone	mm

Qaddinflow	Additional inflow provided in an input file, added to QZU4ZON	m^3/s
Qreginflow	Additional inflow calculated via regression, added to QZU4ZON	m^3/s
QZU4ZON	Upstream inflow to zone	m^3/s
QZU4ZONstart	Upstream inflow at start of time-step	m^3/s
QZU4ZONend	Upstream inflow at end of time-step	m^3/s
QAB4ZON	Outflow from zone (routed runoff)	m^3/s
BW4ZON	Storage in zone	m^3
QSIM	Total runoff at outlet of subbasin	m^3/s

Water balance of zone routing reservoir:

$$BW4_t = BW4_{t-1} + QABZON_t + QZU4ZON_t - QAB4ZON_t \quad (81)$$

$BW4_t$	Water stored in zone routing reservoir	m^3
$QABZON_t$	Local runoff generated by zone	m^3/s
QZU4ZON	Upstream inflow to zone	m^3/s
$QAB4ZON_t$	Total, routed outflow from zone	m^3/s

Outflow of zone routing reservoir:

$$QAB4ZON_t = \int_0^t \frac{BW4(t)}{TAB4} dt \quad (82)$$

$QAB4ZON_t$	Outflow from zone routing reservoir	m^3/s
$BW4_t$	Water stored in zone routing reservoir	m^3
TAB4	Model parameter – recession constant for zone routing	h

2.9 Additional external inflow

In some cases, it may not be possible or feasible to model the whole extent of a catchment. For example, including the Upper Danube when modeling Austria. In cases like this, the user has the option to add external inflow to the model in order to close the water balance. This can be done by either directly providing the inflow timeseries (ADDFLUXCONT = 1), or by calculating the external inflow via linear regression using the runoff from up to three upstream basins as predictors (ADDREGCONT = 1). Depending on the chosen methodology, this additional inflow is called Qaddinflow or Qreginflow.

2.9.1 Direct input: Qaddinflow

If ADDFLUXCONT = 1:

$$QZU4ZON_t = QZU4ZON_t + Qadd_t \quad (83)$$

2.9.2 Internal calculation: Qreginflow

If ADDREGCONT = 1:

$$Qreg_t(NB) = d + \sum_{i=1}^{N} k_i * Qsim_t(NB_{pred,i}) \quad (84)$$

$$QZU4ZON_t = QZU4ZON_t + Qaddinflow_t \quad (85)$$

$Qreg_t(NB)$	Regression-based external inflow added to basin NB at time step t	m^3/s
d	Intercept of the linear regression function	m^3/s
k	Regression coefficient of the i-th predictor (i ≤ 3)	-
$Qsim_t(NB_{pred,i})$	Simulated runoff of the i-th predictor basin at time step t	m^3/s

2.10 Diversions

COSERO offers the option to divert a fraction of the routed cell runoff (QAB4ZON) to another cell (Div_TONZ). The diverted amount is a function of the total cell runoff, a lower (QDIV_LT) and upper (QDIV_UT) threshold, and a diversion ratio (QDIV_RATIO) (Equ. (86)). An example can be seen in Figure 15. If no diversions are implemented, Div_TONZ is set to equal TONZ and the thresholds to 999 in the parameter file.

If no diversion is set, QAB4ZON flows to TONZ. If a diversion is set and QAB4ZON < QDIV_LT, everything flows to TONZ. If QAB4ZON > QDIV_LT, QDIV is calculated according to Equ. (86) and diverted to Div_TONZ, while the rest (QAB4ZON – QDIV) flows to TONZ, with a maximum value of QDIV_UT. Diversions are calculated in the zone routing routine, and QAB4ZON is updated accordingly.

$$QDIV = max \left\{ \begin{matrix} 0 \\ min \left\{ \begin{matrix} (QAB4ZON - QDIV\_LT) * QDIV\_RATIO \\ QDIV\_UT \end{matrix} \right. \end{matrix} \right. \quad (86)$$

Div_TONZ	Cell (NZ) that water is diverted to	-
QDIV	Diverted runoff	m^3/s
QDIV_LT	Lower threshold above which water should be diverted from zone	m^3/s
QDIV_UT	Maximum amount of water that should be diverted from zone	m^3/s
QDIV_RATIO	Ratio of water > QDIV_LT and < QDIV_UT that should be diverted to Div_TONZ	-
TONZ	Cell (NZ) that cell runoff flows into	-

Several practical implications should be noted regarding diverted runoff:

- QSIM of the basin containing the diversion of course doesn't contain the diverted amount anymore,
- Nested basins receiving diverted water do not consider the diverted water's origin basin area in their water balance,
- While there is the possibility to write an output file showing the diverted amounts (monitor_div.txt), this is not implemented in the current version, so the amount of diverted outflow is not directly accessible,

- And it is not possible to divert water out of the modeling domain, so Div_TONZ cannot be zero.

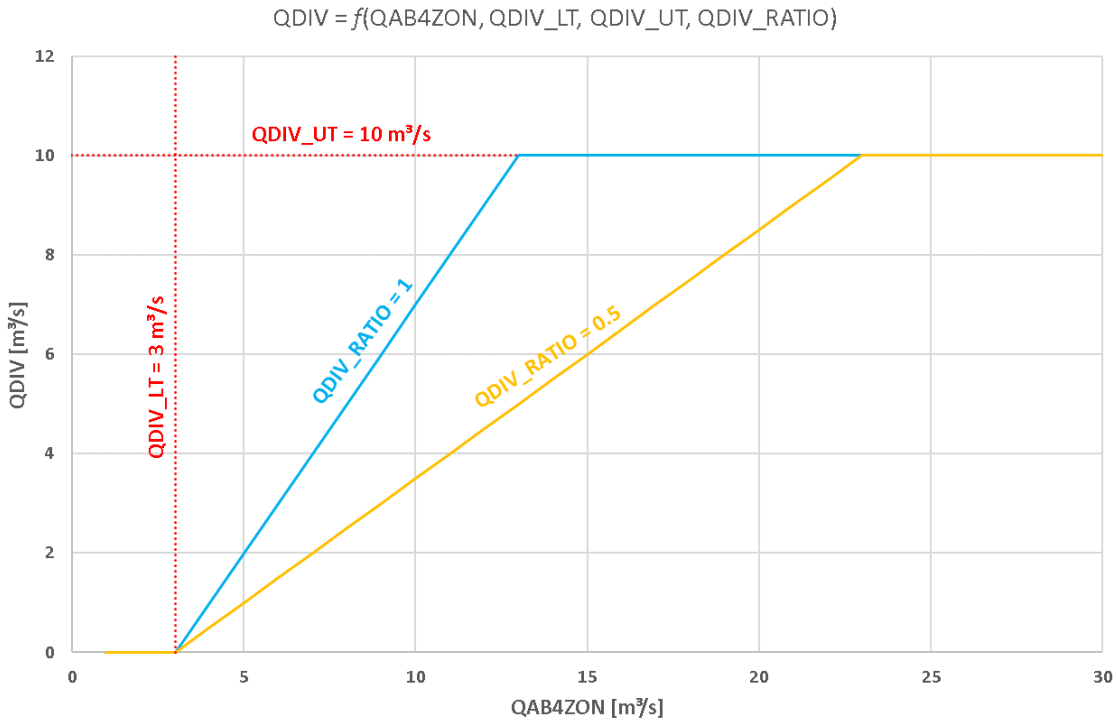


Figure 15. Example of diverted cell runoff (QDIV) dependent on a lower (QDIV_LT) and upper (QDIV_UT) threshold, as well as a diversion ratio (QDIV_RATIO).

2.11 Simulated runoff

After the runoff of all cells has been computed and routed, the total basin runoff is set to the runoff from the most downstream zone. This is the nested basin runoff in m^3/s.

Total, nested basin runoff:

$$QSIM_t = QAB4ZON_{t,IZONE} \quad (87)$$

$QSIM_t$	Simulated basin runoff (also called local runoff Qloc)	m^3/s
$QAB4ZON_{t,IZONE}$	Runoff of most downstream zone IZONE	m^3/s

The local runoff is back-calculated by subtracting the runoff of upstream basins:

$$Qloc_t = QSIM_t - \sum_{i \in NB\_upstream} QSIM_t(i) \quad (88)$$

$Qloc_t$	Local simulated runoff at outlet of basin NB	m^3/s
$QSIM_t$	Total (nested) simulated runoff at outlet of basin NB	m^3/s
$QSIM_t(i)$	Total simulated runoff of upstream basin i	m^3/s

3. Model environment

Generally, the model is a command-line-based program. Although the user can access some program commands via the user interface, e.g. the optimization routines, many settings are defined a priori via text files. Within the program folder, the user must provide an input and output folder (Figure 16). Apart from program settings files (*Defaults.txt*, *MetDefaults.txt*), the input folder also contains files with observed runoff, precipitation, temperature, potential evapotranspiration (optional), and diurnal solar radiation data per month (*radmat.par*). System states at the start of the simulation can be defined in *statevar.dmp*, which is also located in the input folder. The parameters for each zone must be included in a parameter file. The simulation results are stored in the output folder. If OUPUTTYPE = 3 and OUTCONTROL =1 (defined in *Defaults.txt*), a folder "cdr" is required, which must contain a folder "output". The following chapters describe the model environment, the necessary input and output files of the COSERO model. Note that the text files are sensitive to separator characters (tabs vs. spaces), blank lines at the end of the file, and need specific structures.

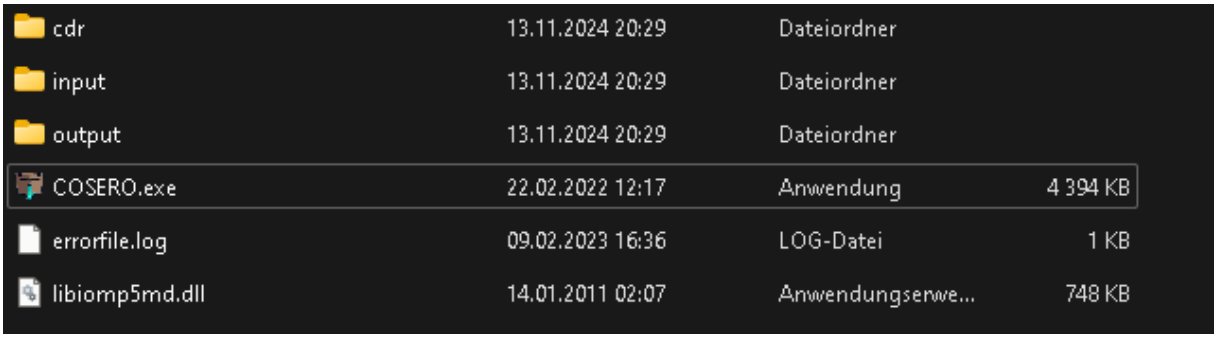


Figure 16. Folder structure for running COSERO.exe.

3.1 Input files

3.1.1 Defaults file – Defaults.txt

In the defaults file, default settings for the hydrological model are defined. It must be present in the input folder. It contains information about the names of the input and output files that are needed for the model run, start and end dates of the simulation, and a control flag to define which model outputs are written into the output folder. Below is an example of a defaults file with its corresponding description. After a keyword (all capitals, e.g., DATAFILE), the default setting must be in the next line. The keywords must not be changed! The maximum length for filenames is set in the file *"maxdim.inc*", which is defined during the compilation process. Typically, a value of 50 characters is used. There must be one more (blank) line after the last setting!

```
This file contains default settings for the COSERO Program.
After a keyword (all capitals, e.g. DATAFILE) the default setting must be in the next line.
The keywords must not be changed!
The maximum length for filenames is defined in the code by MAXFILENAME (usually 50 characters).
The maximum length for the project info is 50 characters.
There must be one more (blank) line after the last setting!

PROJECTINFO (default project info, written into first line of each output file)
```

COSERO-Handbook

DATAFILE (default input data file containing observed discharge, read in from directory "input")
Qobs.txt

PARAFILE (default input parameter file, read in from directory "input")
parameter.txt

IKL (# of snow classes)
9

NCLASS (# of Landuse classes)
10

STARTDATE (start date of simulation period in format yyyy mm dd hh mm)
2010 1 1 0 0

ENDDATE (end date of simulation period in format yyyy mm dd hh mm)
2020 12 31 0 0

SPINUP (length of spin-up period without evaluation [time-steps])
365

OUTPUTTYPE (Sets the output evaluation extent: 1 - only QSIM; 2 - ZRVIEW compatible; 3 - full evaluation)
1

SC_FLAG (Use local subbasin area (EZFL_B, "0") or total upstream catchment area (EZFL_T, "1") for runoff depth / flux calculations)
1

OUTCONTROL (if set to "1", zonal values will be written for every time step: folder cdr/output is needed; very slow; outputtype must be "3"; otherwise set to "0")
0

RUNOFFFILE (default output file for simulated runoff of a single run, written to directory "output")
COSERO.runoff

STATSFILE (default output file for performance statistics of a single run, written to directory "output")
statistics.txt

OPTFILE (default output file for progress of optimization, written to directory "output")
optprogress.txt

ADDFLUXCONT (if set to "1", file Qadd with additional inflow from outside the study area is read in; otherwise set to "0")
0

ADDFLUXFILE (additional inflow in m^3/s added to specified subbasins/zones. Starts with an NB-TONZ mapping header, followed by the time series. Read in from directory "input")
Qadd.txt

ADDREGCONT (if set to "1", file Qreg with regression parameters for estimating inflow from outside the study area is read in; otherwise set to "0")
0

ADDREGFILE (regression parameters (up to 3 predictors) to calculate subbasin inflow based on discharge in other (predictor) subbasins. Read in from directory "input")
reg_para.txt

WRITERASTERS (write state/flux-rasters for use in FEWS)
raster_write.txt

```
BINDATAFILE (default input binary data file, read in from directory "cdr/input", not used)
not_used.dat
```

Figure 17. Example of a Defaults file (.txt).

3.1.2 **Parameter file**

The parameter file in the input folder contains the hydrological model's dimensions and parameters. It has 169 columns (may vary depending on the version) and NZ+2 rows. The first row contains the project name, the second the headers, followed by one row per NZ. Values can be separated by tab or space. The header of each column contains the defined name of the parameter.

Example of a COSERO parameter file:

```
COSERO-Handbook
NB_ IZ_ NZ_ TONZ_ Div_TONZ QDIV_LT_ QDIV_UT_ QDIV_RATIO_
X_COORD Y_COORD WATERBODY_ DFZON_ ELEV_ NC_ ETSLPCOR_
CTMAX CTMIN_ NVAR_ RAINTRT_ RAINCOR_ SNOWCOR_
SNOWTRT_ THRT_ M_ FK_ PWP_ KBF_ BETA_ FKFAK_ H1_ H2_
TAB1_ TAB2_ TVS1_ TVS2_ TAB4_ TAB3_ TAB5_ PCor1_ PCor2_ PCor3_ PCor4_
PCor5_ PCor6_ PCor7_ PCor8_ PCor9_ PCor10_ PCor11_ PCor12_
TCor1_ TCor2_ TCor3_ TCor4_ TCor5_ TCor6_ TCor7_ TCor8_ TCor9_ TCor10_
TCor11_ TCor12_ TMMon1_ TMMon2_ TMMon3_ TMMon4_
TMMon5_ TMMon6_ TMMon7_ TMMon8_ TMMon9_ TMMon10_
TMMon11_ TMMon12_ INTMAX1_ INTMAX2_ INTMAX3_ INTMAX4_
INTMAX5_ INTMAX6_ INTMAX7_ INTMAX8_ INTMAX9_ INTMAX10_
INTMAX11_ INTMAX12_ ETVEGCOR1_ ETVEGCOR2_ ETVEGCOR3_
ETVEGCOR4_ ETVEGCOR5_ ETVEGCOR6_ ETVEGCOR7_ ETVEGCOR8_
ETVEGCOR9_ ETVEGCOR10_ ETVEGCOR11_ ETVEGCOR12_ DAYSDRY1_ DAYSDRY2_
DAYSDRY3_ DAYSDRY4_ DAYSDRY5_ DAYSDRY6_ DAYSDRY7_ DAYSDRY8_
DAYSDRY9_ DAYSDRY10_ DAYSDRY11_ DAYSDRY12_ DAYSWET1_ DAYSWET2_
DAYSWET3_ DAYSWET4_ DAYSWET5_ DAYSWET6_ DAYSWET7_ DAYSWET8_
DAYSWET9_ DAYSWET10_ DAYSWET11_ DAYSWET12_ ETSYSCOR1_
ETSYSCOR2_ ETSYSCOR3_ ETSYSCOR4_ ETSYSCOR5_ ETSYSCOR6_
ETSYSCOR7_ ETSYSCOR8_ ETSYSCOR9_ ETSYSCOR10_ ETSYSCOR11_
ETSYSCOR12_ KMELTRINI_ KSHINI_ KSWINI_ TSOILINI_ BW0INI_
BW1INI_ BW2INI_ BW3INI_ BW4INI_ BAREGR_ CTNeg_
CTRed_DWHCAP_ EVPNS_ EVPSNO_ NSRHOMAX_ PEX2_ PEX3_
SETCON_ SNOWDET_ SOILTYPE_ SRHOMAX_ TSOILMAX_ TSOILMIN_
TVAR_ UADJ_ WHCAP_ SPARE1_ SPARE2_ SPARE3_ GLAC_CT_
GLAC_GLFAKT_ GLAC_ICECOV_ GLAC_TAB_ GLAC_INI_
1 1 1 10 10 999 999 0 -999 -999 0 0.062
2370.935 7 2.2567 10.0672 1.045 8.8589 3.554 1 1 0.2448 0
112.9535 1 0 9185.6553 0.8808 0.8359 0.3052 4.7484 9.1313
130.0378 8.7998 500 1.7697 2951.0833 4.024 1 1 1 1
1 1 1 1 1 1 1 1 0 0 0 0
0 0 0 0 0 0 0 0 -6.944 -6.833 -4.124 -
0.893 3.452 7.067 9.025 9.149 5.487 2.426 -2.696 -6.056 0 0 0 0
0 0 0 0 0 0 0 0 0.65 0.65 0.65 0.65
0.7 0.75 0.75 0.75 0.7 0.65 0.65 0.65 0 0 0 0
0 0 0 0 0 0 0 0 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 0 0 0 5
0.7 0 25 250 0 0 1 0.7 0 0.7 0.3 0.3
9999 9999 0.2 1 1 0.45 15 -5 0 2 0.05 1
1 1 1 0.02 0 8 99999
```

Figure 18. Example of a parameter file (.txt).

3.1.3 **Meteorological data**

The hydrological model uses pre-processed time-series of precipitation and temperature as inputs. Optionally, data of potential evapotranspiration can be used. These input files have an ASCII- or binary format. The meteorological files are described below. These files must also be provided in the input folder.

3.1.3.1 Definition of meteorological input - MetDefaults.txt

The meteorological data used as input is defined in the MetDefaults.txt-file. Keywords (written in CAPITAL letters) must not be changed.

```
This file contains meteorological default settings for the COSERO model

datafiles must have the format; one row for every timestep and without header
[YYYY MM DD hh mm "value for every single zone (sorted by NZ=1 to i"], e.g.
2003 1 2 0 0 0.6 0.8 0.75 .....
2003 1 2 1 0 0.2 0.0 0.5 .....
.
.
;

### USER action necessary below ###

ASCIIorBIN (define, if datafiles are ASCII (0) or Binary (1); relevant for all following files)
0

PRECFILE (input binary/ASCII precipitation file, read in from directory "/input")
P_NZ_24h_1990-2020.txt

TEMPFILE (input binary/ASCII temperature file, read in from directory "/input")
T_NZ_24h_1990-2020.txt

ETPCONTROL (define, how evapotranspiration is calculated; 0 = Thornthwaite, 1 = external datafile)
0

ETPFILE (input binary/ASCII ETP file; relevant, if ETPCONTROL=1)
ETP_NZ.txt
```

Figure 19. Example of a MetDefaults file (.txt).

3.1.3.2 Precipitation

The file containing the precipitation input data is defined in the MetDefaults.txt file. Within this file, the first 5 columns define the time step (YYYY MM DD hh mm). The following columns define the precipitation input for every zone of the hydrological model. The input values must be sorted according to the zone number NZ, e.g. first column is for zone NZ=1, second column for NZ=2, etc. One row is used for every simulation time step. No header is used. It must not contain negative values, NAs, or gaps.

Example of a COSERO precipitation input file with 15-minute timesteps:

```
2003 01 01 00 00   0.103   0.110   0.115   0.113   0.128   0.132   0.165   0.144   …
2003 01 01 00 15   0.150   0.152   0.153   0.147   0.145   0.158   0.110   0.090   …
2003 01 01 00 30   0.050   0.089   0.166   0.118   0.127   0.175   0.151   0.140   …
2003 01 01 00 45   0.010   0.083   0.242   0.140   0.157   0.258   0.211   0.213   …
2003 01 01 01 00   0.110   0.160   0.278   0.192   0.203   0.296   0.198   0.153   …
```

```
2003 01 01 01 15  0.010  0.063  0.191  0.100  0.116  0.205  0.135  0.104  …
2003 01 01 01 30  0.000  0.016  0.049  0.028  0.030  0.053  0.035  0.026  …
2003 01 01 01 45  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  …
2003 01 01 02 00  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  …
2003 01 01 02 15  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  …
2003 01 01 02 30  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  …
2003 01 01 02 45  0.007  0.020  0.061  0.032  0.033  0.057  0.036  0.028  …
...
..
.
```

Figure 20. Example of a precipitation input file (.txt).

3.1.3.3 Temperature

The structure of the temperature input file is identical to the precipitation datafile. Its name is also defined in the MetDefaults.txt file. It can be an ASCII- or binary file and must be provided in the input folder.

Example of a COSERO temperature input file with 15-minute timesteps:

```
2003 01 01 00 00  -4.600  -4.559  -5.066  -4.706  -4.707  -5.215  -4.951  -4.652  …
2003 01 01 00 15  -4.600  -4.559  -5.066  -4.706  -4.707  -5.215  -4.951  -4.652  …
2003 01 01 00 30  -4.600  -4.559  -5.066  -4.706  -4.707  -5.215  -4.951  -4.652  …
2003 01 01 00 45  -4.600  -4.559  -5.066  -4.706  -4.707  -5.215  -4.951  -4.652  …
2003 01 01 01 00  -4.800  -4.750  -5.322  -5.041  -4.963  -5.529  -5.230  -4.918  …
2003 01 01 01 15  -4.800  -4.750  -5.322  -5.041  -4.963  -5.529  -5.230  -4.918  …
2003 01 01 01 30  -4.800  -4.750  -5.322  -5.041  -4.963  -5.529  -5.230  -4.918  …
2003 01 01 01 45  -4.800  -4.750  -5.322  -5.041  -4.963  -5.529  -5.230  -4.918  …
2003 01 01 02 00  -4.565  -4.510  -5.144  -4.945  -4.798  -5.387  -5.146  -4.835  …
2003 01 01 02 15  -4.565  -4.510  -5.144  -4.945  -4.798  -5.387  -5.146  -4.835  …
2003 01 01 02 30  -4.565  -4.510  -5.144  -4.945  -4.798  -5.387  -5.146  -4.835  …
2003 01 01 02 45  -4.565  -4.510  -5.144  -4.945  -4.798  -5.387  -5.146  -4.835  …
...
..
.
```

Figure 21. Example of a temperature input file (.txt).

3.1.3.4 Potential evapotranspiration

Optionally, pre-processed potential evapotranspiration data can be used as additional meteorological input to the hydrological model. In this case, the evapotranspiration flag (ETPCONTROL=1) has to be set in the file MetDefaults.txt. The format and structure are identical to the precipitation and temperature files. If no potential evapotranspiration data is provided, ETP is calculated using the Thornthwaite method. In this case, the mean monthly air temperature values should be provided either as the parameter TMMON in the parameter file or is calculated dynamically for the simulation period.

3.1.4 **Runoff data**

Observed runoff data are stored in the DATAFILE and are defined in the Defaults.txt file. The example below shows a runoff file for a hydrological model consisting of seven subbasins. The simulation time step here is 15 minutes. At each time step, a runoff value is defined in a column for each subbasin. If no observed values are available, *"-0.01"* (or any value less than zero) must

be entered as an error value instead. For a successful model run, all columns have to be separated by blanks (not tabs).

```
COSERO-Handbook
QOBS_1
QOBS_2
QOBS_3
QOBS_4
QOBS_5
QOBS_6
QOBS_7
##########################################################################################
2003   1   1   0   0    12.27   -0.01   50.13   3.78   -0.01   6.51   101.44
2003   1   1   0   15   12.21   -0.01   49.56   3.77   -0.01   6.51   101.31
2003   1   1   0   30   12.16   -0.01   48.98   3.76   -0.01   6.51   100.59
2003   1   1   0   45   12.10   -0.01   48.68   3.75   -0.01   6.35    99.87
2003   1   1   1   0    12.04   -0.01   48.37   3.75   -0.01   6.32   100.92
2003   1   1   1   15   11.97   -0.01   48.07   3.74   -0.01   6.32    99.76
2003   1   1   1   30   11.90   -0.01   47.76   3.73   -0.01   6.32    99.48
2003   1   1   1   45   11.83   -0.01   47.46   3.72   -0.01   6.32   100.24
2003   1   1   2   0    11.77   -0.01   47.10   3.71   -0.01   6.16    98.79
2003   1   1   2   15   11.70   -0.01   46.74   3.71   -0.01   6.16    99.10
...
..
.
```

Figure 22. Example of a runoff input file (.txt).

3.1.5 Additional runoff data (qaddinflow)

If inflow from external basins outside the study area should be considered, ADDFLUXCONT must be set to 1 in the Defaults-file, and an additional input file (ADDFLUXFILE) must be provided. The top line contains a comment, followed by a column listing all NBs and the NZ value to which the additional inflow should be added (TONZ). Then the inflow data should be listed in the same format as in the DATAFILE, including a header line containing YYYY, MM, DD, hh, mm, and the subbasin numbers.

```
Read    NB    and    TONZ   to    define   where   additional    inflow   is    added
NB      TONZ
1          25
2           0
3           0
4           0
5           0
6           0
7           0
##########################################################################################
YYYY   MM   DD   hh   mm   1   2   3   4   5   6   7
2003   1   1   0   0    11.5   0   0   0   0   0   0
2003   1   1   0   15   11.45   0   0   0   0   0   0
2003   1   1   0   30   11.10   0   0   0   0   0   0
2003   1   1   0   45   11.55   0   0   0   0   0   0
2003   1   1   1   0    10.77   0   0   0   0   0   0
2003   1   1   1   15   10.87   0   0   0   0   0   0
2003   1   1   1   30   10.50   0   0   0   0   0   0
2003   1   1   1   45   9.90   0   0   0   0   0   0
```

```
...
..
.
```

Figure 23. Example of an addflux input file (.txt).

3.1.6 Regression parameters (qreginflow)

Besides adding the (optional) external inflow from a file (*qaddinflow*), it is possible to internally calculate the external inflow based on (multiple) linear regression using the runoff from up to three upstream basins. *ADDREGCONT* must be set to 1 in the Defaults-file, and an additional file containing the regression parameters (*ADDREGFILE*) must be provided. The file contains one row per basin that should receive the external inflow, containing the basin number, the cell number where the inflow should be added (TONZ), and the regression parameters. The structure can be seen in Figure 24, and the content is explained in Table 5.

```
NB   TONZ  INT      NUM_PRED SLP_1   PRED_1 SLP_2   PRED_2 SLP_3 PRED_3
511  72909 184.046  2        1.808   131      1.866  218      0      0
568  78950 261.41   2        1.22    511     29.02   519      0      0
```

Figure 24. Example of an addreg input file (.txt).

Table 5. Structure of addreg input file.

NB	Basin which receives additional inflow calculated via (multiple) linear regression
TONZ	NZ in NB where additional inflow is added
INTERCEPT	Intercept of linear regression function
NUMBER_PREDICTORS	Number of predictors in the regression (max. 3)
SLOPE_1	Coefficient of first predictor
PREDICTOR_NB_1	NB of basin that is used as first predictor
SLOPE_2	Coefficient of second predictor, if no second predictor is used set to zero
PREDICTOR_NB_2	NB of basin that is used as second predictor, if no second predictor is used set to zero
SLOPE_3	Coefficient of third predictor, if no third predictor is used set to zero
PREDICTOR_NB_3	NB of basin that is used as third predictor, if no third predictor is used set to zero

3.2 Output files

The results of the hydrological model run are written into different output files in the output folder. A description of the output files generated by the hydrological model is given in Table 6. The output files ending in “B” are written in a binary format used by the visualization software *ZRVIEW*. All other files are in ASCII format and can be viewed with a text editor (e.g., TextPad or Notepad++) or visualized and analyzed in other software products (e.g., Excel, Matlab, or R). Variables denoted with “GEB” are the variables of nested catchments (calculated if SC_FLAG = 1 in Defaults.txt).

Note that, depending on the OUTPUTTYPE defined in Defaults.txt, certain output files are generated or not.

If OUTPUTTYPE = 1 and OUTCONTROL = 1, the zone outputs for a number of system states and fluxes are written to the cdr/output folder, with one file per timestep. Which variables are written depends on the COSERO version.

Table 6. Overview of the model output in the output folder depending on OUTPUTTYPE and OUTCONTROL.

Nr.	Filename	Dimension	Description, content	comment
OUTPUTTYPE = 1, 2, 3				
1	COSERO.plus	basin values	ascii outflows of reservoirs and temperature [mm; °C] QAB123GEB_*NB*, QAB23GEB_*NB*, QAB3GEB_*NB*, TGEB_*NB*	See 3rd window in ZRView
2	COSERO.plusB	basin values	binary version of *COSERO.plus*	ZRVIEW-file
3	COSERO.plus1	basin values	ascii selected system states and fluxes [mm]: BW0GEB_*NB*, BW3GEB_*NB*, SWWGEB_*NB*, PGEB_SUM_*NB*, ETAGEB_SUM_*NB*, QABGEB_SUM_*NB*	See 4th window in ZRView
4	COSERO.plus1B	basin values	binary version of *COSERO.plus1*	ZRVIEW-file
5	COSERO.prec	basin values	ascii precipitation output [mm]: PRAINGEB_*NB*, PSNOWGEB_*NB*	See 2nd window in ZRView
6	COSERO.precB	basin values	binary version of *COSERO.prec*	ZRVIEW-file
7	COSERO.runoff	basin values	total runoff at outlet of each subbasin [m^3/s], and locally generated runoff: QOBS_*NB*, Qloc_*NB*, QSIM_*NB*	See 1st window in ZRView
8	COSERO.runoffB	basin values	binary version of *COSERO.runoff*	ZRVIEW-file
9	statevar.dmp	multi-dimensional (zonal values, snow class values)	state variables at calculation-end	Dump-file
10	statistics.txt	basin values	statistical information based on simulated and observed runoff / objective functions	Text-file
11	topology.txt*	multi-dimensional (zonal values, NB values)	Information on zones/links, flow paths, flow accumulation, and diversions: NZ, NB, IZ, IZQ[1], TONB, TOIZ, FACC[2], FDIST[3], TONB_Div, TIZ_Div, IZQ_Div, QDiv_LT, QDiv_UT, DIV_Ratio	Text-file
Additional if OUTPUTTYPE = 2				
12	CosReg_mm.runoffB	basin values	QOBS_*NB*, QSIM_*NB* in [mm]	ZRVIEW-file
13	monthly_variables.txt	basin values	mean monthly temperature, precipitation, potential and actual evapotranspiration, observed and simulated runoff: T_*NB*, P_*NB*, ETP0_*NB*, ETAT_*NB*, QOBS_*NB*, QSIM_*NB*	Text-file

14	var_glac.txt	basin values	glacier melt and -accumulation: glacmelt_*NB*, glacacc_*NB*	Text-file
15	var_MET.txt	basin values	meteorological data: evapotranspiration, temperature, total precipitation, rain, and snow ETATGEB_*NB,* ETP0GEB_*NB,* PGEB_*NB,* TGEB_*NB,* PRAINGEB_*NB,* PSNOWGEB_*NB*	Text-file
Additional if OUTPUTTYPE = 3 & OUTCONTROL = 0				
16	long-term_annual_means.txt	basin values	Long-term mean annual variables, system states, and fluxes: TQOBS, Qobs, Qsim, TDAYS, AWHCAP, BF, BFALF, BW0, BW1, BW2, BW3, BW4, BWI, CTA, CTP, DATAN, DATAP[4], DATAT[5], DELTAS[6], ETAG, ETAI, ETAS, ETAT, ETP0, ETPE, ETPR, MELTR, MELT, N, PNETRAIN, PNET, PRAINSOIL, PRAIN, PSNOW, P, QAB, QAB1, QAB2, QAB3, QEX2, QVS0, QVS1, QVS2, SCOV, SH, SMELT, SRHO, SWWKLMAX, SWWKLMIN, SWW, TOTALS[7], GLACMELT, GLACACC, TSOIL, T	Text-file
17	long-term_seasonal_means.txt	basin values	Long-term mean seasonal variables, system states, and fluxes (same as annual)	Text-file
18	monitor.txt	basin values	QOBS_ *NB,* QSIM_ *NB,* P_ *NB,* ETAT_ *NB,* DELTAS_ *NB,* SWW_ *NB,* BW0_ *NB,* BW3_ *NB* in [mm]	Text-file
19	monitor_sb*NB*.txt	basin values	qobs_*NB*, qsim_*NB*, bf_*NB*, bw0_*NB*, bw1_*NB*, bw2_*NB*, bw3_*NB*, bw4_*NB*, bwi_*NB*, cta_*NB*, deltas_*NB*, etag_*NB*, etai_*NB*, etas_*NB*, etat_*NB*, etp0_*NB*, melt_*NB*, meltr_*NB*, prainsoil_*NB*, prain_*NB*, psnow_*NB*, p_*NB*, qab1_*NB*, qab2_NB, qab3_NB, qab_*NB*, qex2_*NB*, qvs0_*NB*, qvs1_*NB*, qvs2_*NB*, scov_*NB*, smelt_*NB*, swwklmax_*NB*, swwklmin_*NB*, sww_*NB*, glacmelt_*NB*, glacacc_*NB*, tsoil_*NB*, t_*NB* in [mm]	Text-file
20	rundepth.txt	basin values	Qobs and Qsim in [mm] for every basin	Text-file
Additional if OUTPUTTYPE = 3 & OUTCONTROL = 1 (cdr/output folder needed)				
21	00_avg_Year.txt	mean zonal values	mean annual zonal values	Text-file
22	01_avg_Jan.txt	mean zonal values	mean monthly zonal values	Text-file
23	02_avg_Feb.txt	mean zonal values	mean monthly zonal values	Text-file
24	03_avg_Mar.txt	mean zonal values	mean monthly zonal values	Text-file

25	04_avg_Apr.txt	mean zonal values	mean monthly zonal values	Text-file
26	05_avg_May.txt	mean zonal values	mean monthly zonal values	Text-file
27	06_avg_Jun.txt	mean zonal values	mean monthly zonal values	Text-file
28	07_avg_Jul.txt	mean zonal values	mean monthly zonal values	Text-file
29	08_avg_Aug.txt	mean zonal values	mean monthly zonal values	Text-file
30	09_avg_Sep.txt	mean zonal values	mean monthly zonal values	Text-file
31	10_avg_Oct.txt	mean zonal values	mean monthly zonal values	Text-file
32	11_avg_Nov.txt	mean zonal values	mean monthly zonal values	Text-file
33	12_avg_Dec.txt	mean zonal values	mean monthly zonal values	Text-file
34	13_avg_Winter.txt	mean zonal values	mean seasonal zonal values	Text-file
35	14_avg_Spring.txt	mean zonal values	mean seasonal zonal values	Text-file
36	15_avg_Summer.txt	mean zonal values	mean seasonal zonal values	Text-file
37	16_avg_Fall.txt	mean zonal values	mean seasonal zonal values	Text-file

[1] IZQ = order of zones within a subbasin, upstream to downstream

[2] FACC = flow accumulation FACC (count number of upstream zones)

[3] FDIST = flow distance FDIST (count number of downstream zones)

[4] DATAP = input (uncorrected) precipitation

[5] DATAT = input (uncorrected) temperature

[6] DELTAS = storage change

[7] TOTALS = total storage change

3.2.1 Statevar file - statevar.dmp

The statevar file contains the system states at the end of the calculation. Included are the system states for the interception storage, soil module, snow module, glacier model, and the different storages of the reservoir chain of the hydrological model. Depending on the model component, they are assigned to system states and have different dimensions. NB stands for basin, IZ for the internal numbering of zones within a basin, and, in terms of snow variables, NKL for the internal numbering of snow classes within a zone. An example for a statevar.dmp file is given in Figure 25.

```
statevar-date: 2005  9 30  0  0

NB IZ BWIZON  BW0ZON  BW1ZON  BW2ZON  BW3ZON  BW4ZON  QZU4ZONstart_T TSOILZON
SCOVZON SWWKLMAXZON SWWKLMINZON BWLRGLAC_B ACCGLAC_B redmelt
 1  1 0.0000 64.0507  0.1533  10.2198 103.1669 10.1390  0.0000    2.6389    1.0000   38.8169    0.0000
0.0000   0.0000  0.7000
 1  2 0.7208 55.3774  0.1356   8.9053  96.9719  8.3003  0.0000    2.6389    1.0000   38.9043    0.0000
0.0000   0.0000  0.7000
 1  3 0.0000 61.5158  0.1486   9.9708 101.9943  9.7812  0.0000    2.6389    1.0000   38.8028    0.0000
0.0000   0.0000  0.7000
```

```
 1   4 0.0000 61.5158   0.1486    9.9708 101.9943   9.7812     0.0000       2.6389      1.0000     38.8028       0.0000
0.0000    0.0000  0.7000
...
..
.
NB IZ NKL     KSWIN       KSHIN    KMELTRIN     KSRHOIN     KSWUMIN
 1  1   1    0.0000      0.0000      0.0000      0.0000      0.0000
 1  1   2    0.5002      1.9039      0.0000      0.2627      0.5002
 1  1   3    1.6238      5.6494      0.0000      0.2874      1.6238
 1  1   4    8.0637     25.9849      0.1677      0.3103      7.8961
 1  1   5   38.8169    123.6886      0.3428      0.3138     38.4741
 1  2   1    0.0000      0.0000      0.0000      0.0000      0.0000
 1  2   2    0.5410      1.9039      0.0000      0.2841      0.5410
 1  2   3    1.6646      5.6494      0.0000      0.2947      1.6646
 1  2   4    8.1555     26.0403      0.1720      0.3132      7.9834
...
..
.
```

Figure 25. Example of a statevar.dmp-file.

3.2.2 **Statistics file – statistics.txt**

The statistics file contains information about the most recent model run. In the header, some information about the simulation is provided. This includes the time and date the simulation was started, the names of some input files, the start and end dates, the number of time steps simulated, and the spin-up time. In the main body of the file, criteria describing the quality of the hydrological simulation are tabulated (Table 7). They provide information about the quality of the hydrological simulation for every subbasin. They are calculated for the timeseries excluding the spin-up time.

Table 7. Overview of the objective function listed in the statistics file

Nr.	Objective function	Token	Equation
1	Nash-Sutcliffe-Efficiency	NSE [-]	$NSE = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q}_o\right)^2}$
2	Kling-Gupta-Efficiency	KGE [-]	$KGE = 1 - \sqrt{(r-1)^2 + (\alpha-1)^2 + (\beta-1)^2}$ $\beta = \frac{\mu_s}{\mu_o} \quad \alpha = \frac{\sigma_s}{\sigma_o}$
3	correlation of QSIM and QOBS	CORR [-]	$\rho_{X,Y} = \frac{\operatorname{cov}(X,Y)}{\sigma_X \sigma_Y}$
4	Coefficient used in the KGE, representing the variability of prediction errors, ratio of SigSim/SigObs	ALPHA [-]	$\alpha = \frac{\sigma_s}{\sigma_o}$
5	Coefficient used in the KGE, representing a bias term, ratio of mSim/mObs	BETA [-]	$\beta = \frac{\mu_s}{\mu_o}$
6	Coefficient used in the adjusted KGE instead of alpha, ratio of CVsim/CVobs	GAMMA [-]	GAMMA = ALPHA/BETA
7	Adjusted Kling-Gupta-Efficiency	KGEadj [-]	$KGE_{adj} = 1 - \max\left(0, \sqrt{(\rho-1)^2 + (\beta-1)^2 + (\gamma-1)^2}\right)$
8	mean square error	MSE [m³/s]²	$MSE = \frac{1}{N} \sum_{t=1}^{N} (Q_{sim,t} - Q_{obs,t})^2$
9	Mean absolute error	ABSERR [m³/s]	$MAE = \frac{1}{N} \sum_{t=1}^{N} \lvert Q_{sim,t} - Q_{obs,t} \rvert$
10	bias between mean simulated and observed values, bias of mean (daily) error	BIAS [m³/s]	$BIAS = \frac{\sum (Q_{sim,t} - Q_{obs,t})}{N}$
11	Mean QSIM	MSIM [m³/s]	$\bar{Q}_{sim} = \frac{1}{N} \sum Q_{sim,t}$
12	Mean QOBS	MOBS [m³/s]	$\bar{Q}_{obs} = \frac{1}{N} \sum Q_{obs,t}$
13	standard deviation of QSIM	SIGSIM [m³/s]	$\sigma_{sim} = \sqrt{\frac{1}{N} \sum (Q_{sim,t} - \bar{Q}_{sim})^2}$

14	standard deviation of QOBS	SIGOBS [m³/s]	$\sigma_{obs} = \sqrt{\frac{1}{N}\sum(Q_{obs,t} - \bar{Q}_{obs})^2}$
15	maximum positive error	MAXPOS [m³/s]	$MAX_{pos} = \max(Q_{sim,t} - Q_{obs,t})$
16	maximum negative error	MAXNEG [m³/s]	$MAX_{neg} = \min(Q_{sim,t} - Q_{obs,t})$
17	maximum absolute error	ABSMAX [m³/s]	$MAX_{abs} = \max(\lvert Q_{sim,t} - Q_{obs,t} \rvert)$
18	NSE of the largest n peaks	PDIFF [-]	
19	autocorrelation of error	ACERR	
20	number of sign changes	NSC [-]	
21	largest value of cumulative sum of error	SUMERR	

List of Tables

Table 1. Important variables of the COSERO model. Flux variables represent sums over the time step. State variables give the water storage at the end of the time step. 6

Table 2. Model parameter dimensions 7

Table 3. Description of all model parameters. **Sensitive** ones are denoted in bold, and those also typically **included in model calibration** in bold and underlined. 8

Table 4. Topology indices in the parameter file. 12

Table 5. Structure of addreg input file. 52

Table 6. Overview of the model output in the output folder depending on OUTPUTTYPE and OUTCONTROL. 53

Table 7. Overview of the objective function listed in the statistics file 57

Table 8. References related to the application of COSERO. 62

Table 9. COSERO Landcover classes (NC_) 65

Table 10. A priori information on the parameter INTMAX as a function of land use and month of year. 65

Table 11. A priori information on the parameter ETVEGCOR as a function of land use and month of year. 66

Table 12. Assignment of CORINE Land Cover codes (CLC_CODE) to COSERO land use classes (COSERO_Class) 67

Table 13. Overview of COSERO Parameters derived from Hydrobod maps 68

List of Figures

Figure 1. Schematic representation of the state formulation with system states S, input I, output O, and time t. 3

Figure 2. Illustration of the spatial discretization of the Mur catchment. The overall catchment is subdivided into smaller sub-catchments, which are then further divided into a finer grid of spatial units. This hierarchical spatial representation allows the model to capture the heterogeneity of the catchment and the underlying hydrological processes at different scales (Burgholzer 2017). 4

Figure 3. COSERO model structure, including model parameters, system states, and fluxes. 5

Figure 4. Relationship between solid and liquid precipitation as a function of temperature 13

Figure 5: Schematic overview of the calculation of ETA within the different modules, including relevant model parameters. Note that actual evapotranspiration is also a function of the system states. 16

Figure 6. Schematic view of the snow cover in COSERO. (a) Composition of one snow class. (b) View of one grid cell including five snow classes, each of which is composed in the way shown in (a). Snowfall is distributed log-normally throughout the classes (b). Note that the snow depth (KSHIN) is given in meters while all other parameters regarding snow are given in millimeters of snow water equivalent (Frey and Holzmann 2015). 19

Figure 7. Share of freshly fallen snow assigned to each snow class (total number of snow classes IKL = 5) based on a log-normal distribution as a function of the model parameter NVAR. 20

Figure 8. Calculation of REDMELT for $PSNOW_t > 0$. 22

Figure 9. Change of the melt factor reduction factor REDMELT over time, dependent on new snow fall PSNOW. In COSERO, Scrit is hardcoded to 5mm, but here three different REDMELT curves are shown to compare the influence of this threshold (Scrit = 2, 5, 10). REDMELT is constrained by CTRED (here 0.7) and 1 (=no reduction of melt factor). 22

Figure 10. Example of the seasonal variation of the melting factor due to changes in the albedo of the snow cover. 23

Figure 11. Conceptual melting processes of snow and ice. 32

Figure 12. Diurnal variation of global radiation per month at Mt. Hoher Sonnblick (via Nachtnebel et al. (2009a)). 34

Figure 13. Determination of BFALF as a function of soil moisture, permanent wilting point (PWP), field capacity (FK) and model parameter FKFAK (see Equ. (65)). 36

Figure 14: Approximation of the runoff generation as a function of soil moisture and the exponent parameter BETA. 38

Figure 15. Example of diverted cell runoff (QDIV) dependent on a lower (QDIV_LT) and upper (QDIV_UT) threshold, as well as a diversion ratio (QDIV_RATIO). 45

Figure 16. Folder structure for running COSERO.exe. 46

Figure 17. Example of a Defaults file (.txt). 48

Figure 18. Example of a parameter file (.txt). 48

Figure 19. Example of a MetDefaults file (.txt). 49

Figure 20. Example of a precipitation input file (.txt). 50
Figure 21. Example of a temperature input file (.txt)..... 50
Figure 22. Example of a runoff input file (.txt). 51
Figure 23. Example of an addflux input file (.txt). 52
Figure 24. Example of an addreg input file (.txt). 52
Figure 25. Example of a statevar.dmp-file. 56

Appendix

List of publications implementing COSERO

Table 8. References related to the application of COSERO.

Reference	Category	Reference Type
APCC (2014)	Climate Change Impact Assessment	Report
Bica et al. (2011)	Precipitation Analysis and Correction	Project Report
BMLFUW (2005)	Hydrological Modeling Studies and Applications	Report / Hydrological Atlas of Austria
Burgholzer (2017)	Model Development and Parameter Estimation	MSc Thesis
Buttinger (2018)	Climate Change Impact Assessment	MSc Thesis
Buttinger et al. (2018)	Climate Change Impact Assessment	Conference Abstract
Eder et al. (2005)	Hydrological Modeling Studies and Applications	Journal Article
Ehrendorfer (2022)	Model Development and Parameter Estimation	MSc Thesis
Ehrendorfer and Herrnegger (2023)	Model Development and Parameter Estimation	Conference Abstract
Ehrendorfer et al. (2023)	Hydrological Modeling Studies and Applications	Conference Abstract
Ehrendorfer et al. (2024)	Climate Change Impact Assessment	Conference Abstract
Enzinger (2009)	Hydrological Modeling Studies and Applications	MSc Thesis
Feiel (2018)	Hydrological Modeling Studies and Applications	MSc Thesis
Frey and Holzmann (2015)	Model Development and Parameter Estimation	Journal Article
Fuchs (1998)	Hydrological Modeling Studies and Applications	MSc Thesis
Herrnegger et al. (2008)	Hydrological Modeling Studies and Applications	Conference Abstract
Herrnegger et al. (2010a)	Precipitation Analysis and Correction	Conference Abstract
Herrnegger et al. (2010b)	Water Balance Studies	Conference Abstract
Herrnegger and Nachtnebel (2011)	Water Balance Studies	Conference Abstract
Herrnegger et al. (2012)	Model Development and Parameter Estimation	Conference Abstract
Herrnegger and Nachtnebel (2012b)	Precipitation Analysis and Correction	Conference Abstract
Herrnegger and Nachtnebel (2012a)	Precipitation Analysis and Correction	Conference Abstract
Herrnegger (2013)	Precipitation Analysis and Correction	PhD Thesis
Herrnegger et al. (2014)	Water Balance Studies	Conference Abstract
Herrnegger et al. (2015)	Model Development and Parameter Estimation	Conference Abstract
Herrnegger et al. (2015)	Precipitation Analysis and Correction	Journal Article

Reference	Category	Reference Type
Herrnegger et al. (2016)	Model Development and Parameter Estimation	Conference Abstract
Herrnegger et al. (2018)	Precipitation Analysis and Correction	Journal Article
Herrnegger et al. (2020)	Model Development and Parameter Estimation	Project report
Kling (2002)	Hydrological Modeling Studies and Applications	MSc Thesis
Kling (2006)	Water Balance Studies	PhD Thesis
Kling and Nachtnebel (2009)	Model Development and Parameter Estimation	Journal Article
Kling et al. (2006)	Hydrological Modeling Studies and Applications	Journal Article
Kling et al. (2012)	Climate Change Impact Assessment	Journal Article
Kling et al. (2014)	Hydrological Modeling Studies and Applications	Journal Article
Kling et al. (2015)	Hydrological Modeling Studies and Applications	Journal Article
Klingler (2020)	Large-Sample Hydrology and Data	MSc Thesis
Klingler et al. (2020)	Large-Sample Hydrology and Data	Journal Article
Klingler et al. (2021c)	Large-Sample Hydrology and Data	Journal Article
Klingler et al. (2021b)	Large-Sample Hydrology and Data	Journal Article
Klingler et al. (2021a)	Large-Sample Hydrology and Data	Conference Abstract
Klotz et al. (2015)	Model Development and Parameter Estimation	Conference Abstract
Klotz et al. (2017b)	Model Development and Parameter Estimation	Journal Article
Klotz et al. (2017a)	Model Development and Parameter Estimation	Conference Abstract
Koch and Herrnegger (2019)	Climate Change Impact Assessment	Conference Abstract
Lerche (2022)	Hydrological Modeling Studies and Applications	MSc Thesis
Maier et al. (2024)	Precipitation Analysis and Correction	Conference Abstract
Mehdi et al. (2021)	Climate Change Impact Assessment	Journal Article
Nachtnebel et al. (1993)	Hydrological Modeling Studies and Applications	Project Report
Nachtnebel (2008)	Forecasting and Real-Time Applications	Project Report
Nachtnebel et al. (2009a)	Forecasting and Real-Time Applications	Project Report
Nachtnebel et al. (2009b)	Forecasting and Real-Time Applications	Project Report
Nachtnebel et al. (2010)	Forecasting and Real-Time Applications	Project Report
Nachtnebel et al. (2011)	Climate Change Impact Assessment	Project Report
Nachtnebel et al. (2013)	Forecasting and Real-Time Applications	Project Report
Omonge et al. (2019)	Hydrological Modeling Studies and Applications	Conference Abstract
Omonge et al. (2022)	Hydrological Modeling Studies and Applications	Journal Article
Pulka (2021)	Forecasting and Real-Time Applications	MSc Thesis
Pulka et al. (2021)	Forecasting and Real-Time Applications	Journal Article

Reference	Category	Reference Type
Pulka et al. (2022)	Forecasting and Real-Time Applications	Conference Abstract
Pulka et al. (2023)	Precipitation Analysis and Correction	Conference Abstract
Pulka et al. (2024)	Precipitation Analysis and Correction	Journal Article
Salamon (2020)	Model Development and Parameter Estimation	MSc Thesis
Santos et al. (2019a)	Forecasting and Real-Time Applications	Conference Abstract
Santos et al. (2019b)	Forecasting and Real-Time Applications	Conference Abstract
Santos et al. (2020)	Forecasting and Real-Time Applications	Conference Abstract
Santos et al. (2021c)	Forecasting and Real-Time Applications	Journal Article
Santos et al. (2021a)	Forecasting and Real-Time Applications	Conference Abstract
Santos et al. (2021b)	Forecasting and Real-Time Applications	Conference Abstract
Schößwendter (2018)	Hydrological Modeling Studies and Applications	MSc Thesis
Schulz et al. (2015)	Model Development and Parameter Estimation	Project Report
Stanzel (2012)	Hydrological Modeling Studies and Applications	PhD Thesis
Stanzel and Nachtnebel (2010)	Climate Change Impact Assessment	Journal Article
Stanzel et al. (2008)	Forecasting and Real-Time Applications	Journal Article
Stanzel et al. (2018)	Climate Change Impact Assessment	Journal Article
Stanzel and Kling (2018)	Climate Change Impact Assessment	Journal Article
Wesemann (2021)	Hydrological Modeling Studies and Applications	PhD Thesis
Wesemann et al. (2015)	Climate Change Impact Assessment	Conference Abstract
Wesemann et al. (2017)	Model Development and Parameter Estimation	Conference Abstract
Wesemann et al. (2018a)	Hydrological Modeling Studies and Applications	Journal Article
Wesemann et al. (2018b)	Model Development and Parameter Estimation	Journal Article
Zeitfogel et al. (2022)	Model Development and Parameter Estimation	Conference Abstract
Zeitfogel et al. (2024a)	Model Development and Parameter Estimation	Conference Abstract
Zeitfogel et al. (2025)	Water Balance Studies	Journal Article

Parameter Tables

Landcover Classes (NC_)

Table 9. COSERO Landcover classes (NC_)

Land Cover Code	German name	Land cover
1	Bebaute Siedlungsflächen	built-up areas
2	Ackerland	farmland
3	Grünland	meadows and pastures
4	Laubwälder	deciduous forests
5	Nadelwälder	coniferous forests
6	Mischwälder	mixed forests
7	Vegetationsarme Flächen	sparsely vegetated areas
8	Gletscher	glaciers
9	Wasserflächen	water bodies
10	Feuchtgebiete	wetlands

INTMAX

Table 10. A priori information on the parameter INTMAX as a function of land use and month of year.

NC_	Land use / Vegetation	Month											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	built-up areas	0	0	0	0	0	0	0	0	0	0	0	0
2	farmland	0	0	0	0.3	0.7	1	1	1	1	0.5	0	0
3	meadows and pastures	0	0	0	0.3	0.7	1	1	1	1	0.5	0	0
4	deciduous forests	1	1	1	2	3	4.5	4.5	4.5	4	3	1	1
5	coniferous forests	3.5	3.5	3.5	3.7	3.8	4	4	4	4	3.8	3.5	3.5
6	mixed forests	1	1	1	1.3	1.7	2	2	2	2	1.5	1	1
7	sparsely vegetated areas	0	0	0	0	0	0	0	0	0	0	0	0
8	glaciers	0	0	0	0	0	0	0	0	0	0	0	0
9	water bodies	0	0	0	0	0	0	0	0	0	0	0	0
10	wetlands	0	0	0	0.5	1	1.5	1.5	1.5	1	0.5	0	0

ETVEGCOR

Table 11. A priori information on the parameter ETVEGCOR as a function of land use and month of year.

NC_	Land use / Vegetation	Month											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	built-up areas	0.7	0.7	0.7	0.75	0.8	0.9	0.9	0.9	0.8	0.75	0.7	0.7
2	farmland	0.4	0.4	0.4	0.5	0.65	0.95	0.95	0.95	0.9	0.85	0.5	0.4
3	meadows and pastures	0.5	0.5	0.6	0.8	0.9	1	1	1	0.9	0.85	0.7	0.6
4	deciduous forests	0.6	0.6	0.6	0.6	0.9	1.2	1.2	1.2	1	0.6	0.6	0.6
5	coniferous forests	0.8	0.8	0.8	0.8	1	1.05	1.05	1.05	1	0.8	0.8	0.8
6	mixed forests	0.6	0.6	0.6	0.6	0.9	1.1	1.1	1.1	0.9	0.6	0.6	0.6
7	sparsely vegetated areas	0.65	0.65	0.65	0.65	0.7	0.75	0.75	0.75	0.7	0.65	0.65	0.65
8	glaciers	0.85	0.85	0.85	0.85	0.85	0.9	0.9	0.9	0.85	0.85	0.85	0.85
9	water bodies	0.4	0.4	0.4	0.6	0.9	1.1	1.1	1.1	0.9	0.5	0.4	0.4
10	wetlands	0.9	0.9	0.9	1	1.2	1.2	1.2	1.2	1.2	1.1	0.9	0.9

CORINE Landcover Classes

Table 12. Assignment of CORINE Land Cover codes (CLC_CODE) to COSERO land use classes (COSERO_Class)

CLC_CODE	COSERO_Class
111	1
112	1
121	1
122	1
123	1
124	1
131	7
132	7
133	7
141	3
142	3
211	2
212	2
213	2
221	2
222	4
223	4
231	3
241	2
242	2
243	2
244	3
311	4
312	5
313	6
321	3
322	5
323	6
324	6
331	7
332	7
333	7
334	7
335	8
411	10
412	10
421	10
422	10
423	10
511	9
512	9
521	9
522	9
523	9

Estimation of COSERO Parameters from spatially distributed soil hydraulic maps

The soil module and its downstream components can be parameterized using spatially distributed soil information. This parameterization approach was initially developed by Herrnegger et al. (2020), who derived COSERO soil parameters from soil hydraulic property maps created for Lower Austria within the Hydrobod project (Eder et al. 2011, Sotier et al. 2017). The derived COSERO parameters and the corresponding HYDROBOD maps are described in Table 13. The soil hydraulic information provided in the Hydrobod projects was recently regionalized to cover all of Austria (Zeitfogel et al. 2023, Zeitfogel et al. 2025). The resulting maps are available for download at https://doi.org/10.5281/zenodo.13752163 (Zeitfogel et al. 2024b).

Table 13. Overview of COSERO Parameters derived from Hydrobod maps

COSERO-Parameter	Definition	Hydrobod maps	Description
M [mm]	storage capacity of the soil	Soil water storage [mm]	Total soil water storage capacity (excluding residual water content) in mm
BETA [-]	parameter to compute runoff generation as a function of soil moisture	g1 [mm]	G-values*, capillary flow [mm] of the top soil layer (0-20 cm)
KBF [h]	recession constant for simulating outflow from the soil module with a linear reservoir	k1 [mm/d]	Saturated hydraulic conductivity of the top soil layer (0-20 cm)
TVS1 [h]	recession constant for simulating percolation from the surface flow module	k2 [mm/d]	Saturated hydraulic conductivity of the mid soil layer (20-50 cm)
TVS2 [h]	recession constant for simulating percolation from the inter flow module	k3 [mm/d]	Saturated hydraulic conductivity of the bottom soil layer (50-100 cm)
H1 [mm]	outlet level of reservoir for simulating surface flow	pv2 [mm]	Total pore volume (excluding residual water content) in mm of the mid soil layer (20-50 cm)
H2 [mm]	outlet level of reservoir for simulating inter flow	pv3 [mm]	Total pore volume (excluding residual water content) in mm of the bottom soil layer (50-100cm)
TAB1 [h]	recession constant for simulating surface flow	g2 [mm]	G-values*, capillary flow [mm] of the mid soil layer (20-50 cm)
TAB2 [h]	recession constant for simulating inter flow	g3 [mm]	G-values*, capillary flow [mm] of the bottom soil layer (50-100 cm)
* Notice that G has units of length and can be thought of as a net or effective value of capillary head (KINEROS – Documentation and User Manual, 1990).			

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